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HE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

PROCEEDINGS.

SESSION 1907—1908.

VOL. XXIII.

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THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

SESSION 1907-1908.

The first meeting of the Session was held at the Institute, Dudley, on Saturday, the 28th September, 1907.

The President (Mr. Robert Buchanan) presided during the first part of the meeting.

The Minutes of the last annual meeting were read, approved, and signed.

Messrs. Francis Greenhouse, S. G. James, William Ludlow, W. W. Maddams, F. F. Sharpe, A. J. Smith, and C. Willetts, Jun., were elected members of the Institute.

The Vice-President, Mr. W. J. Foster, then took the chair, and the President delivered the following address :—

ADDRESS BY THE PRESIDENT.

(Mr. ROBERT BUCHANAN).

A few years ago, when visiting the Antiquarian Museum in Edinburgh, I was shown numerous articles of stone and of bronze, most of them for use in battle. "When, in the world's history," I asked, "was the Stone Age?" The Attendant replied that the present was the Stone Age. As I looked surprised at the statement, the courteous attendant showed me a case of stone battle axes, hammers, and maces recently received from the South Sea Islands, as proof of his statement. Forty years ago the Assiniboine Indians of Canada cooked their Buffalo meat by immersing it in water held in a Buffalo hide held up at the corners, throwing into the water stones which had been made red-hot. This latter fact can scarcely be cited as proving that the Red Indian was still in the Stone Age, but only that he had not reached the Age of Iron.

My friend of the Museum assured me that in the world as a whole there are no definite periods of time which we may call Ages of Stone, Bronze, or Iron, though for certain countries of the world such definitions may be correctly applied.

A little reflection will show that this view is the correct one, and proof exists which shows that each Age overlapped into the succeeding one, a result indeed which we might expect. The mind craves for well-drawn lines of demarcation to mark the various stages of advance, and rightly holds in honour the memory of those known as having made notable discoveries, and so helped to fix the character of the period in which they lived and worked. And yet these were "heirs of the ages," and had had handed down to them a wealth of mental power and practical experience gained throughout unnumbered generations.

Lord Kelvin once said that the greatest and most original discovery ever made was that of the unknown man of the far-away past, who first produced fire by artificial means.

So we find, when we come to consider the founding of metals, that we are but the lately added links of a chain which connects us with the realities of a dim Antiquity.

Even Hiram of Tyre, " cunning to work all works in brass," who cast the great bronze pillars for the Temple of Solomon, had learnt from his father, a Tyrian brassfounder, and so placed his foundry in the clay grounds in the plains of the Jordan.

We read of the great pillars, twenty-seven feet long by five feet nine inches outside diameter, which Hiram cast, and of the great molten sea fifteen feet from brim to brim, and an handbreadth thick. Also of the ten wonderful bases with four wheels under each, " and the work of the wheels was like the work of a chariot wheel, their axle-trees, and their naves, and their felloes, and their spokes were all molten."

The great pillars may have been made without patterns or models, but that is improbable. It is certain that the bases mentioned were made from patterns or models, for we are told that " after this manner he made the ten bases; all of them had one casting, one measure, and one size " (I. Kings, Chap. 7).

The art of patternmaking as well as of founding is thus very ancient. How such great quantities of molten bronze were melted and handled we have no knowledge. Not improbably it was by the method Krupp used in casting a 100 ton steel ingot, namely, by having a small army of men, and casting from crucibles.

Earlier in Jewish history we are told that Goliath of Gath went into battle with a helmet of brass upon his head, brass greaves upon his legs, on his body a brass coat-of-mail weighing one hundred and fifty-six pounds, and in his hand a spear the head of which was of iron, and weighed between eighteen and nineteen pounds. In addition he had a target of brass between his shoulders. Mention is made in the Book of Joshua of the vessels of brass and of iron captured at the taking of Jericho, and the Prophet Isaiah says, " Who hath formed a god, or molten a graven image; that is profitable for nothing."

In these early times then, the brassfounder's art had existed long enough to have reached a very high stage of development.

It is to be noted that the brass mentioned in all old writings is what we now know as bronze; an alloy of copper and tin. What we now know as brass is an alloy of copper and zinc, and was first used hundreds of years after the times of which I have been speaking. The same applies to the casting of iron as it was only within comparatively recent times that what we now know as cast iron was discovered.

To come nearer home, it may be noted that the Highlands of Scotland had no Bronze Age, but passed directly from the Stone to the Iron Age. Ireland had a great Bronze Age, and in Ireland have been found the finest examples of ancient bronze work we possess. In Ireland was found a sandstone mould, containing a bronze spear-head, with the runner head and " git " attached, the mould divided exactly as we would divide a chill mould to-day. This sandstone mould and bronze casting I have seen and examined.

It is remarkable that the production and utilisation of cast iron came very late in the life history of metals. Iron and steel had been produced directly from iron ores thousands of years before cast iron comes into notice as a metal of utility.

It is very probable that cast iron had often been made accidentally before its utility was perceived. The inception and development of the blast furnace had a most important result. So far as the Western world is concerned, it caused wrought iron and steel to be produced by the indirect method of first making pig iron, and from the latter making wrought iron and steel. The direct methods for producing iron and steel still linger in India, Africa, and other parts of the world where the poverty of the workers and their ignorance of mechanical appliances, and possibly their prejudices, cause them to adhere to the old time-honoured method of direct production. However, there is this to be said: The iron and steel produced by these crude methods is unsurpassed in quality by the very best produced in the Western world with all the science and mechanical appliances we have at our command.

The first time that cast iron came into prominence in England was in 1543, in the reign of Henry the Eighth, when Ralph Hogge, at Bucksteed, in Sussex, made a cast iron cannon. Probably this was cast directly from the blast furnace.

Hogge had as an assistant Peter Baude, a Frenchman, whom he had brought from France to show him improved methods of founding. This shows that the founding of cast iron had been in considerable use on the Continent of Europe, at least so far as France is concerned. Baude evidently began business on his own account as a maker of cast iron cannon, for we are told that John Johnson, a " covenanted servant " of Baude's, exceeded his master " in his art of casting ordnance, making them cleaner and to better perfection." Thomas Johnson, son of John Johnson, and mentioned as being a " special workman " in and before the vear 1595, cast for the Earl of Cumberland forty-two " great pieces of ordnance," each weighing 6,000 pounds. Fairbairn hazards the opinion that the change from the "blast bloomery" to the blast furnace took place early in the sixteenth century. I think it very improbable that the change was so late as that. Were the first blast furnace installed in the year 1501 it is most improbable that the art of casting iron had progressed so rapidly as to admit of the casting of cannon only forty-two years later.

The Sovereigns of England owned two blast furnaces in the Forest of Dean, these being erected about the year 1550, in the reign of King Edward the Sixth. By the time Elizabeth was on the throne the English founders had evidently outdistanced their rivals in the excellence of their cannon, as there was a considerable export trade to the Continent in these engines of war.

In the reign of James the First there was a great crisis in the iron trade. An enactment was made forbidding the cutting of timber for the purpose of making charcoal for use in ironworks, the forests in Sussex being alone exempt.

At the time this Act was passed the annual output of iron in Britain was 180,000 tons, a very considerable amount.

The scarcity of wood to make charcoal caused the making of iron so increasingly difficult that by the year 1740 the output of iron had dropped to the paltry amount of 17,350 tons per annum. There must have been a relaxation of the law forbidding the use of wood for the making of charcoal, for we find that charcoal iron was being made in South Staffordshire prior to the year 1619, and up to the year 1646, when the Civil War began.

In the year 1619 Dud Dudley, one of the great pioneers of iron manufacture, and one of the most pathetic figures in English industrial life, by the influence of his father obtained from King James a Patent to make iron by a new method. Dud Dudley was a natural son of one of the Earls Dudley, and was born in the town were we are now met. His Patent was declared to be related to "the mistere and arte of melting iron ewre (ore), and of making the same into cast workes or bars, with sea coles, or pit coles, in furnaces with bellowes." He made the pig iron at Pensnett, and refined it "into merchantable good bar iron" at Cradley Forges.

He goes on to say, "I also made all sorts of cast iron wares, as Brewing Cysterns, Pots, Morters, and better and cheaper than any yet were made in these Nations, with charcoles."

By a combination of Ironmasters interested in the making of charcoal iron he got put out of his works at Pensnett and Cradley, but began again to make pig iron from " pitcoles," at the Himley Furnaces. Not having a forge, and the necessary refining furnaces for treating the pig iron for the production of bar iron, he was under the necessity of selling his pig iron to the charcoal ironmasters. We need not be surprised to receive Dudley's complaint of these ironmasters not only " detaining his stock, but also disparaging the iron." The charcoal ironmasters by some means got the Himley Furnace into their hands, and Dudley built a new, large furnace near Sedgley. This furnace was twenty-seven feet square, and was built of stone. What the height was we do not know. The bellows to blow the furnace, Dudley says, " were larger than ordinary Bellowes are, in which work he made 7 Tuns of iron per week, the greatest quantity of Pit-Cole iron that ever yet was made in Great Britain." Then he goes on to tell of how " the Author was thrown out of his works, and the Bellowes of his new Furnace and Invention, by riotous persons cut in pieces, to his no small prejudice and loss of his Invention of making Iron with Pit-cole Sea-cole etc."

Dudley was acquainted with the three varieties of pig iron, though we may differ from some of his conclusions.

" Give me leave to mention that there be three sorts of cast iron. (1) The first sort is gray iron. (2) The second sort is Motley Iron, of which one part of the Sowes, or Piggs, is gray, the other part is white intermixt. (3) The third sort is called White Iron; this is almost as white as Bell-Mettle, but in the Furnace is least fined and the most Terrestrial." (Evidently meaning impure). " Of the three, the motley iron is somewhat more fined, but the gray iron is most fined and more sufficient to make Bar-Iron with, and tough Iron to make Ordnance, or any cast Vessels, being it is more fined in the Furnace, and more malleable and tough than the other two sorts before mentioned."

He mentions selling many " tuns of pigg or cast iron " at four pounds per " tun " with good profit, when " charcole pig iron hath been sold at six pounds per Tun, yea at seven pounds per Tun."

He sold bar iron at twelve pounds per " tun " when charcoal iron was selling at from £15 to £18 per ton. Dudley mentions the millions of tons of slag and cinder available, the product of many years of working the " Bloomery " furnaces, some of which was being used at the pig iron furnaces, and was found to be easier of fusion than was the iron ore. The charcoal furnaces made from two to three tons of " pigg " or cast iron in 24 hours, but Dudley expresses his contentment with one ton in 24 hours, " which once he attained before his Bellowes were riotously cut."

Dudley's claim for the Patent granted to him by King James the First does not disclose what his method or secret was, but Dr. Percy says that probably it was by coking the coal before using it. Dudley received from Charles the First, in the face of much opposition, a second Patent for a term of 14 years.

On the outbreak of the Civil War Dudley joined the army of King Charles as an officer, and was involved in the general ruin of the King's party. In the Forest of Dean some officers, friends of Cromwell, endeavoured to make iron in "Potts of Glasshouse clay," but failed. They endeavoured to get Dudley to advise them, but he contented himself by predicting that they would not succeed. One final glimpse we get of this great Englishman After the Restoration he petitioned Charles the Second for a renewal of his Patent, but his first petition was lost. To his second petition he got no reply from the Royal founder of the "Royal Society," and Dud Dudley's life went out, as did his furnaces, in a gloom of apparently utter and complete failure. With a period of 250 years to bridge, it is difficult to know the whole man, but to me his is a character most fascinating. He saw the country over-run by lawless and sturdy beggars, for employment was scarce, and the iron trade declining owing to the completed destruction of the forests and consequent scarcity of charcoal. His declared intention was to build up again the iron trade of England by the use in ironmaking of the small coal which was being thrown aside as waste materials at the collieries. It was reserved for one of a later generation, living in happier times, and under more favourable conditions, to succeed where he failed. A study of the life of Dud Dudley, however, leaves us with the knowledge that early in the 17th century, in South Staffordshire, a great man was born. He lived and worked, triumphed and failed, fought and suffered, and exhibited through all an invention, perseverance, patriotism, and fortitude which compel our admiration.

THE FIRST CAST IRON COOKING POT.

In the year 1709 Abraham Darby, a native of Birmingham, was in charge of a brass foundry in Bristol. For hundreds of years the Dutch have been famous as bell-founders, and it was from Holland that Darby obtained his skilled men. Abraham Darby conceived the idea of casting cooking pots of iron, and set his brass founders to do so, but they failed. Possibly they did not want to succeed. With the assistance of a Welsh boy, John Thomas, Darby himself managed to cast a pot successfully. The pot was cast in a wooden moulding box; probably these were in regular use for brassfounding at that period. The iron was, almost certainly, melted in a crucible, with charcoal as fuel, the coking of coal not yet being known. The secret of how to make cast iron pots was kept by Darby and Thomas and their successors for over one hundred years. Dr. Percy was told by a lady member of the Darby family, living about sixty years ago, that the secret consisted of using fine sand, and venting the sand thoroughly for the passage of the gases liberated when the iron was poured. As brassfounders now use a closer and finer sand than do ironfounders, the explanation is, I think, inadequate. Until the coking of coal was accomplished probably the melting of the iron was the greatest difficulty.

It is worthy of note that betwixt the first recorded instance of a cast iron cannon being made in England, and the first cast iron cooking pot, there was a period of 166 years.

THE MAKING OF COAL INTO COKE.

Abraham Darby's partners in the brassfoundry not liking his experimenting, he and John Thomas removed to Coalbrookdale, in Shropshire, and there built a blast furnace.

Abraham Darby the Younger, seeing the supply of charcoal was fast failing, between the years 1730-1735 experimented with coal with a view to making it act as a substitute for charcoal. This he latterly succeeded in doing, using the same method as is employed when making wood into charcoal. Then followed the test of the coke in the blast furnace. The incident is well-known of how Darby, after a vigil of six days and nights at the blast furnace, fell asleep so soon as he saw the iron flow from the furnace, and was carried home, still sleeping, by the workmen. To blow his blast furnace, with coke as fuel, Darby used bellows, the largest then made. Darby had found out the necessity of a larger volume of air when using coke than was necessary when using charcoal. It will be remembered that Dud Dudley used bellows larger than ordinary. Thus to Abraham Darby the Younger belongs the honour of being the first declared inventor and user of coke for the reduction of iron ores in a blast furnace. It is beyond the power of imagination, or of words, to describe the benefits his enterprise has conferred upon the iron trade of the world, and upon civilisation.

Blowing engines are said to have been first used at the Carron Ironworks, in Stirlingshire, founded by Dr. John Roebuck in the year 1760, and Roebuck gave James Watt financial support and encouragement in perfecting his steam engine for which he obtained a patent in 1769.

Coke as a fuel for blast furnaces still holds the field, and is likely to do so, but the reciprocating engine of James Watt is gradually being ousted from its place by the gas engine using blast furnace gas. Thus, as the production of pig iron increased, and its cost declined, so the foundries increased in numbers and in capacity, and their products reached all parts of the world.

THE EVOLUTION OF THE FOUNDRY CUPOLA.

In the Stückofen, or High Bloomery, wrought iron was made, but by allowing the bottom to wear deeper, thus forming a well below the single tuyere, and using more fuel and charging the furnace higher, cast iron was produced. The slag was not drawn off, but was retained to keep the oxygen of the blast from decarburising the iron. When the furnace was so used it was known as a Blauofen furnace. Percy says, " Hence nothing could be more gradual than the development of the modern blast furnace in which cast iron alone is obtained." Again he says, " When blast furnaces are built slightly of brick only, and hooped or cased with iron, they are called Cupola furnaces, to distinguish them from massive furnaces like those of Congreaves." The foundry cupola is thus very closely related to the blast furnace as first developed from the Blauofen furnace. It differs only in minor details, and here and there cupolas may be found having only one tuyere, and again there may be as many as sixteen, but in every case the cupola is used for the melting of iron, and not for the reduction of ores.

The proper working of cupolas is a subject which is receiving from foundrymen in general a considerable amount of attention, but there are still considerable numbers of them who have the haziest ideas as to what is taking place as melting proceeds. In this respect, however, as in the science and practice of foundry work, the British Foundrymen's Association is doing a good and useful work which is certain to have the effect of raising the progressive foundryman to a higher plane of knowledge and practice.

MALLEABLE CAST IRON.

This is an important industry in South Staffordshire, and is worthy of notice. In 1722 Reaumur, a Frenchman, published the fact that the heating of cast iron castings embedded in red oxide of iron softened the metal perfectly, and took away its brittle character. In 1804 Samuel Lucas got a Patent for doing what appears to be the same thing that Reaumur did eighty-two years before. Lucas recommended the cementation of the castings in a steel convertor, or other suitable furnace, during five or six days and nights, with " ironstone ore, or some of the metallic oxides, lime, or any combination of these."

The castings were packed in cylindrical cast iron pots, and each casting was surrounded with iron ore or hammer scale. There were difficulties; probably the kind of pig iron necessary was not clearly understood, and the patent remained unworked for some time. Latterly Thomas Lucas, of Chesterfield, brother of the patentee, overcame the difficulties, and began casting cutlery, calling it " run steel." The pig iron he used was white Cumberland hematite. The method of making malleable castings described and patented by Lucas in 1810 is exactly the method employed in South Staffordshire to-day. There have been only two modifications of any importance. One is the use of the cupola for melting the iron instead of melting it in crucibles, though the latter method is still very largely employed. The other modification is the employment of gas, instead of coal, for annealing the castings. The high quality of the malleable castings made in South Staffordshire is known all over the world, and recently an American expert said of some malleable castings made in this district that neither in America nor elsewhere in England had he met with any of such high quality and finish. Notwithstanding that gratifying testimony to the excellence of the products, there is undoubtedly great occasion for the employment of scientific knowledge, and scientific accessories. The malleable castings trade has suffered much from the attitude adopted by most of those engaged in it, that it is, as it were, a secret process. There are, of course, refinements of operation known to, and naturally kept secret by, the individuals concerned, but that is true of most industries and most individuals. When people put on superior airs of how much they could say if they only cared to speak, one is apt to conclude that such reticence is quite as often a cloak for ignorance as a hiding of superior knowledge. This industry will truly advance when those practising it come out into the open and tell us of their failures. I am content that they should keep their successes to themselves. Judging the heat of the annealing oven by the human eye, skilled though it be, is subject to too many causes of inaccuracy of vision to be reliable. Some annealers aid their judgment by placing balls of sand in positions where they may be reached and withdrawn, if they have " fritted," or fused enough to stand withdrawal. That leads up to the question of why scientific accessories are not more used. The use of Seger Cones as guides to the temperatures employed would be of enormous benefit, but better still would be the Recording Pyrometer. The latter would give accurate details of all the course of annealing, and what is most important, would get rid of the personal equation so far as the annealer is concerned.

THE FOUNDRY APPRENTICE.

It will readily be granted that a continuous supply of young skilled foundrymen, able to take the places of those passing out of the business by death or other causes, is of enormous importance. It is to the foundries engaged in engineering work, or to " jobbing " foundries, we must look for our supply of skilled men. Foundries engaged in repetition work produce workmen able and skilled, but with a restricted outlook and experience. In America they have a four years' apprenticeship, and even then there is a distinct shortage in the supply. One result is that some of the Technical Colleges give courses of training in foundry work, and several of the proprietors of large foundries are following the example. I am old-fashioned enough to believe that the seven years' apprenticeship common to foundries in this country is not a day too long. To that is due the fact that to-day, as for many years past, in Great Britain we have the finest and most skilled foundry workers in the world. Technical Schools and Colleges have a great message for the foundry worker, and especially for the foundry foreman or manager, but for a training in practical work they are inadequate. As a substitute for apprenticeship they may be necessary, but happily we are not yet faced by that difficulty. It should be realised by all proprietors of foundries, and all having authority in foundries, that the proper training of the apprentice is a measure of the highest economy, and an important step in self-preservation. If we in our works add technical instruction to the practical experience of our apprentices, that is good; but do not let us wait until apprenticeship is dying out, and thus be forced into looking for substitutive methods which will almost certainly be inadequate.

FOUNDRY ARCHITECTURE AND EQUIPMENT.

In this country it is almost invariably the case that foundries are designed by people who know nothing of foundry work, and are so self-satisfied as to be able to do without the help of those who do know. The result in many cases is what may be mildly described as a miserable failure. So it often is with the equipment of the foundry in respect of the various machines and tools to be employed. An instance of this came under my notice recently. In the particular foundry they were using expensive moulding machines, and getting results which were less favourable than others were securing without machines. On enquiry it was ascertained that these moulding machines were installed by an official who had been talked into buying them, but knew nothing whatever about moulding machines of his own knowledge. Whether moulding machines may advantageously be introduced into a particular foundry is oftentimes not easily answered even by the expert foundryman. In the higher and most skilled lines of foundry work the moulding machine is practically out of court, and even in some of the simpler forms of castings it no more than holds its own. A railway chair, for instance, is a simple form of casting, but the moulding machine has yet to be made which will beat the results obtained by hand methods. This only shows that not everyone who has power to introduce moulding machines is also a good judge of whether they should be introduced or no. There is undoubtedly a large and useful field for the moulding machine, especially the simpler forms of these. Ofttimes, it has to be admitted, the success or failure of the machine depends upon the man at the machine. When they fail to do what is expected of them it has first to be considered whether they have failed for reasons pertinent to the machine, or for reasons pertinent to the man working it. When they prove a success, it is not difficult to find claimants to the honour. I have been asked if I could account for the less output obtained in this country from moulding machines compared with that claimed to be obtained in America. My reply is that the home worker can't be, and won't be, driven like the Pole or Hungarian. However Radical or Socialistic in politics our workmen may be, they are strong Conservatives in trade matters. The workman is no more to be blamed for this than another is for being Conservative in politics. Each fears that change will leave him in worse case than he was before.

Changes of method of work can only be wholly successful when it allows the workman, as well as the capitalist, to better his position. Wide and sustained recognition of this fact is the only way to get the whole-hearted co-operation of workmen when changes of method of work become necessary.

THE COMMERCIAL SIDE OF FOUNDRY WORK.

Only in the most highly organised businesses is the commercial side fully developed. The highest practical skill may be exercised in a business and yet have results of the most disappointing character, often ending in the Bankruptcy Courts. This is due to the absence, on the part of the people conducting the business, of sufficient commercial aptitude or training. This is truest of the smaller business concerns, the practical and commercial management being often in the same hands, the practical side being much the stronger. In such cases there is almost no grasp of the immense importance of taking into account the "Standing Charges" and the less obvious outlays. Often they have no idea what their "Standing Charges" are. When estimating they take the cost of the metal and of moulding, and add a certain percentage which they believe will leave them a profit. Of that they are not certain, as they have no data to guide them as to whether it will or no. Having heard that Messrs. So and So are offering to supply at a certain price (which may, or may not, be true), and being certain they can work cheaper than Messrs So and So, they quote a lower price than the one they have heard mentioned. Messrs. So and So may be on the high road to ruin, and their competitors kindly accompany them part of, if not the whole of, the way. Businesses may possibly be carried on successfully without any profound technical knowledge, but sound commercial knowledge there must be. There is now available, for use by founders, a considerable amount of data, and methods of costing, which will give near approximations to the true cost of castings.

In his recent presidential address to the members of the British Foundrymen's Association, Mr. Herbert Pilkington, a past president of this Institute, rightly called attention to the enormous importance of this subject. Did this matter of commercial training receive due recognition we would meet with fewer instances of insane competition and disastrous climaxes.

PROGRESS OF THE INDUSTRY.

With every advance in engineering the foundry has had to advance also; were it not so, many improvements in engineering practice would have been stifled at their birth. We are now at a transition period for many foundries. The plants which for a great number of years have been engaged in casting parts for reciprocating engines have had to tackle the problems and difficulties of the steam turbine. That they have successfully solved the problems and overcome the difficulties, the turbines of enormous power recently made for marine propulsion, prove. I have no expectation that the practical foundryman of to-day, and of by-gone days, is likely to be surpassed in the future. What I hope to see is a higher type of Foremen and Managers. Even now there are men of the highest accomplishments in these positions, but generally in their several positions they are much inferior to the men they control. The ideal is that they should equal the best of their men in practical skill, steadiness, and solidity of character, and surpass them in technical knowledge. I am glad to give expression to a firm belief that this condition of matters is being recognised, and that there is now apparent a sense of shortcomings in the direction indicated, and a desire to rise to a higher knowledge of the founder's art.

That this Institute should foster and increase this desire for higher knowledge, and so far as lies in its power, satisfy the desire, is, I am sure, a fulfilling of the aims for which the Institute was founded.

THE DISCUSSION.

The VICE-PRESIDENT: I propose a very cordial vote of thanks to the President, Mr. Robert Buchanan, for his inaugural address. Mr. Buchanan is a President whom every member of the Institute will admire, and there is perhaps no better authority upon foundry work, particularly light foundry work, in this district than he. As most members know, he was the first President of the British Foundrymen's Association. The consumption of iron per head of the population in any country is often referred to as a standard of that country's civilisation. It is remarkable what a transposition of figures the last couple of decades has seen in respect of the manufacture of iron of the world. Twenty years since, the British Empire was predominant as a producer of this aid to civilisation. Such have been the changes that to-day our output only occupies the third place. To take pig iron as a basis of calculation, last year the make for the whole of the Empire was eleven and a half million tons. Germany, on the other hand, last year produced over thirteen million tons of pig iron. The United States, marvellous to record, smelted almost twice the tonnage of the German furnaces. These figures are surprising. But there is greater cause for wonder still, in that, added to their own remarkable output, Germany and America actually imported more pig iron of British make than any of our other export markets. It should be borne in mind also that this imported pig iron is in those countries competing with our own, converted into manufactured goods, a process requiring the expenditure of at least something like seven times the amount of labour necessary for the production of the raw iron, even counting the coal getting prior to the pig making. A comparison of the iron exports of this country and Germany and America at the present time is very interesting. The total pig iron exports from Great Britain in August of this year was 164,094 tons; from Germany 28,318 tons, and from the United States 31,750 tons. Now let us look at our own imports. The total imports of pig iron, steel, and iron and steel manufactured into this country last August were 78,203 tons; the previous year in the same month the total was 90,562 tons; and in August, 1905, 107,638 tons. The present condition of the iron trade, alike in our own country and the competing nations I have mentioned, is full of food for thought, and its lessons should not be lost upon an Institute such as this.

Mr. MOSES MILLARD: In seconding the vote of thanks that has been proposed to the President for his address, I should like to express my appreciation of the research and enquiry its composition must have involved. Mr. Buchanan's references to the work of Dud Dudley appeal to me very strongly. As the iron and steel manufacturing district where Dud lived and operated, I consider we have failed in our duty in not having long since erected a monument to his memory. Indeed, as the oldest of the iron and steel making countries of the world, the duty has long lain at the door of Great Britain to erect a suitable memorial. Until either a national or a Staffordshire monument has been raised to Dud Dudley the debt which we owe to a distinguished ancestor of the present honoured Earl of Dudley will never be paid. In the course of his address the President made refernce to the matter of apprentices in the ironfoundry, and expressed his preference for the seven years apprenticeship system, attributing to it much of the best work afterwards turned out in foundry practice. I entirely agree with him concerning the value of the apprenticeship system. And I go further than the President; I consider it would be wholly to the advantage of our industries if the practice were exercised, as in years back it used to be, to a very much greater extent than it is at present. The President refers to the growing recognition of the necessity for a larger technical training in foundry work, and closes his address with the words : " That this Institute should foster and increase this desire for higher knowledge, and, so far as lies in its power, satisfy the desire is, I am sure, a fulfilling of the aims for which the Institute was founded." In this sentence Mr. Buchanan seems to forget our work for the past forty years It may be his personal modesty that makes him speak thus; but something is due to the Institute of which he stands at the head. Mr. Buchanan argues as though the Institute was just starting its career. For many years, however, as a matter of fact, it has been performing valuable educational work in this district, and as an old ex-President, and as the oldest member of the Institute, I always like to see that work recognised.

PROFESSOR TURNER : We are exceeding our usual custom in discussing a President's inaugural address, but as the example has been set I should like to make a short reference to it. I have listened to Mr. Buchanan with very considerable pleasure for several reasons. I am desirous to take this opportunity to congratulate Mr. Buchanan upon his election as President of this important body—a body which, as Mr. Millard has very correctly remarked, has done a large amount of very useful and successful work during the last twenty-five years, and probably longer. I have had the pleasure of acquaintance with the President's operations for over twenty years. I have seen how he has gradually advanced from one successive position to another, until now he has been elected to preside over the deliberations of this Institute. That he will fill his new office with satisfaction to himself and the members I am certain. I was interested in the reference at the very commencement of the address to the Antiquarian Museum at Edinburgh. I have visited that Museum more than once, and there is a great deal of useful knowledge to be got there. I only wish that we in Birmingham possessed any Museum approaching that of Edinburgh, either with respect to the extent of ground it covers or the character of its contents. Even on the metallurgical side of the Museum, unexpected as it might well be supposed in a literary and art centre like Edinburgh, there are beautiful models of up-to-date metallurgical and allied manufacturing plant. The President reminded us that it was remarkable how late the production and utilisation of cast iron came in the history of metals; and further, that direct methods for producing iron and steel still linger in India, Africa, and other distant parts of the globe. The President attributed this adherence to direct production methods mainly to the poverty of the natives, and to their ignorance of mechanical appliances. While in some degree this deduction may be correct, I am inclined to think that in many countries or districts the reason is a much more simple one. Many of these native iron workers depend upon charcoal for their fuel. Many of them are nomadic, and when they have been in one district for a length of time all the available charcoal becomes exhausted. They have then perforce to move elsewhere to a fresh source of supply, and so they continue moving from place to place, taking their little blast furnace plant along with them. The President speaks of the probability of ordnance having been cast upon the Continent well prior to the year 1543, when the first mention occurs of the casting of cannon in this country, only forty-two years subsequent to the erection of the first blast furnace in England. I am quite at one with Mr. Buchanan in his deductions. I have seen in the yard of the Tower of London one or two large cannon which were sent over to Ireland in the reign of Henry VIII., and brought back to the Tower, and the date of this ordnance is certainly twenty years, if not more, before the piece mentioned by the President as having been cast in Sussex in 1543. A large cast iron gun was cast in London in 1516. The introduction of the manufacture of cast iron in this country was certainly earlier than the date suggested by Fairbairn. I am inclined myself to fix the date quite as early as 1490. As nearly as can be reckoned at this distance of time, the discovery of America and the application of cast iron were simultaneous events; indeed, cast iron manufacture may have commenced even earlier than the date attaching to the finding of the New World. The President's story of how the first cast iron cooking pot came to be invented, and the particulars he gives of the work of Abraham Darby and John Thomas, are attractive reading. But I should have thought that cast iron cooking pots were in vogue before 1709. Considering that fire grates and chimney pieces were apparently cast about the same date as the first cannon, I should have expected to find that cooking pots would have been cast prior to the date set out in the address. Why the long interval of time between the admitted date of the casting of ordnance and the invention of the cast pot, if 1700 for the latter achievement is to be regarded as anything like the accurate date, I fail to understand. No doubt the casting of pots would be a somewhat more difficult accomplishment than the production of cannon; still, I cannot see the necessity for the long interval of inventive idleness.

Mr. H. SILVESTER: I should like to associate myself with Professor Turner in his expressions of appreciation of the Presidential address to which we have just listened.

The Institute is to be congratulated on possessing a President who, speaking as an expert of long standing, is able to lay before us in such an interesting manner the rise, the progress, and prospects of the foundry industry.

Not the least valuable points in the address are the views as to the training of the skilled foundryman, and the breezy optimism as to the future of the trade.

Like Mr. Millard, I was glad to hear the eulogy of Dud Dudley, and as I listened I could not help imagining that possibly it might be permitted to those who in life—deserving success—had apparently failed, to visit the scenes of their struggles, and hear an appreciation of their work such as we have listened to from the President to-night.

There was an omission of the name of one pioneer of the iron trade from Mr. Buchanan's address, to whom I should like to refer. Mr. John Wilkinson, of Bradley, Broseley and Bersham, near Wrexham, was associated with the improvements in founding—necessitated by the engines of Watt, and, unlike Dud Dudley, was financially successful.

As is well known in industrial history, Wilkinson made the first iron boat, which someone has said was the forerunner of all subsequent iron or steel vessels. He should also be remembered and honoured by this Institute because he built the first blast furnace in the township of Bilston, where he is stated to have erected a cast iron chapel, which contained a cast iron pulpit. In the Sunday School in connection with this chapel he is said to have advised the teaching of writing, and the expense of pens, ink, and paper being urged as a reason for not giving such lessons, suggested the use of light moulding boxes filled with sand for the copy book, and iron skewers as pens. "By such teaching," he said, "you will do something to keep the devil "off them all their lives. If that don't increase the number of "saints, it will decrease the number of fools."

Wilkinson also cast cannon for the Peninsular War, and was the first to successfully found and bore cylinders for Watt's engines. His passion for iron was strong in death, for by his directions he was buried in a cast iron coffin, and the grave was surmounted by a cast iron monument.

I thought these remarks on a remarkable man would interest you, Mr. President, and also the Institute.

Mr. Walter Macfarlane: Mr. Buchanan has favoured us with a painstaking and able address. It is full of interesting industrial history, many incidents of which might form a starting point for an exhaustive enquiry. I quite concur with the criticism of Mr. Millard and other speakers respecting the charge of neglect which rightly lies at the door of South Staffordshire respecting the absence of any public memorial to the valuable work accomplished in this very district nearly three centuries ago. Before to-day I have publicly pronounced this neglect a disgrace to the Black Country, and I should like on this occasion to emphasise my remarks to the fullest possible degree. The visitor to St. Paul's Cathedral is asked to "look around him" if he seeks any memorial to the architect. The same tribute may be paid to Dud Dudley, and with equal truth when the history of the Black Country comes to be considered. Yet I none the less think, and I believe this Institute thinks also, that some tangible memorial to his worth should be erected in our midst. There are other Worcestershire and Staffordshire ancient names of note that might well be similarly honoured. One of these has been prominently brought before us in the President's address; I refer to Abraham Darby. Darby was a Birmingham man, and his family at one time occupied the Wren's Nest Farm, Dudley. Abraham Darby himself, as the President has reminded us, branched out into the brassfoundry business at Bristol. He went over to Holland, then noted for its bell casting, and brought from there Dutch experts, who assisted in making the Bristol venture a success. At the same time there was at the Bristol works the Welsh lad, John Thomas, a farmer's boy, and he and his master set to work together, and succeeded in casting a new form of cooking pot. Financial difficulties developed as time went on, and caused Darby and Thomas to move to Coalbrookdale, in Shropshire. There, working with barred doors and guarded premises, these early inventors pursued and perfected their industry, and laid the foundation of Coalbrookdale's fame for the highest class of foundry work. I was greatly interested in the closing portion of Mr. Buchanan's address, where he speaks of present-day conditions. He speaks very hopefully and gratifyingly of the spirit of present-day ironfounders, that they are anxious to mend their past defects, and to possess themselves of technical and scientific trade knowledge. My own experience enables me happily to bear out these remarks. Year by year we enrol an increased number of foundrymen in our technical classes in this district, and I believe the same is true of some other iron manufacturing districts of the Kingdom. So crowded are some of the local classes becoming that I am somewhat perplexed in attempting to find suitable accommodation for all the students. Complimentary reference has been made in the course of this discussion to the circumstance that Mr. Buchanan is a Scotchman, and we have heard something concerning many prominent positions that are filled by Scotchmen. It is somewhat singular that in a career of forty years the Institute has never before been presided over by a North Countryman. This circumstance, however, is no more strange than that when the West of Scotland Iron and Steel Institute was founded its presidents for the first nine successive years were Englishmen. At present (as in the past) the presidential chair in Scotland is worthily occupied by an Englishman.

Mr. L. D. THOMAS : There are certain advantages and disadvantages attaching to the office of President, and one of the former is that by an unwritten law there is usually no debate upon a President's address. In Mr. Buchanan's case, however, the rule has been departed from, probably because the members could not restrain their admiration of the paper. Mr. Buchanan's concluding remarks upon to-day's foundry practice are of a very practical sort, and it would be a great advantage if some of them were acted upon. It must be admitted that foundry practice in South Staffordshire has hitherto been a great deal too much based upon rule of thumb knowledge. There are a few notable exceptions, and some of them of a very notable character, but the bulk of the founders are still a long way behind. It is very gratifying to learn from Mr. Buchanan that an awakening is now in progress, and the establishment of the British Foundrymen's Association is another evidence in point. I should like to record my belief—and this circumstance should act as an encouragement also—that a distinct future of increased prosperity is before those foundries and foundrymen who do attain scientific knowledge, and who adopt scientific methods of production. Mr. Buchanan has traced the progress of the iron age, and the Vice-President has spoken of the wonderful progress which Germany and America have made in iron manufacture in recent years. I rejoice in that progress; I am in no way jealous of it. As Britishers we should be proud that the pioneers of the American iron and steel trade went from this side, and without English, and Welsh, and Scotch aid America's vast natural minerological and iron and steel resources would have remained useless and unutilized. And the Americans themselves are the first to admit the truth of this. It is neither wise nor profitable to regret the growth of Germany and America as iron-producing countries. It is true that these nations, once among our leading customers, are now our chief iron and steel competitors, but, for better or worse, the die has long ago been cast, and we cannot alter it if we would. One lesson, however, we may learn, and that an important one. In the past new ideas or new proposals emanating from works' managers or from inventors in this country have been too often pooh-poohed or obstructed, while these same ideas taken to the United States have frequently proved the life-blood of American or Continental prosperity. Although the consumption of iron in America is greater per head of the population than here, it is a striking fact that our over-sea iron and steel exports exceed those of America, Germany, and France put together. And this, in face of the fact, too, that precisely opposite to the condition of things in America, we are obliged to import great quantities of the raw materials for our furnaces and works. I must bear my testimony to the justice and appropriateness of Mr. Millard's remarks touching the work accomplished by this Institute. It is my sincere hope that this valuable educational influence will extend with the years, and that each succeeding President of the Institute will find his position an increasingly honourable and responsible one.

I may also add that the paper on "The Foundry Cupola, and how to manage it," read by the President before this Institute some time back, is well worthy of the notice of members in conjunction with this address. It is lamentable to see how some cupola attendants go about their work, causing loss to their employers, and also helping to turn out inferior castings. On the other hand, it is amusing to talk to some of these men, and ask questions regarding the working of the cupola; they jog along heedless of results. I trust that this address, and the paper I have just mentioned, will set ironfounders and others connected with castings thinking more about this important matter.

Mr. Richard Edwards: As one of the founders of the Institute, I am sure that we have every reason for complimenting Mr. Buchanan upon the happy way in which he has dealt with his subject, and I beg most sincerely to add my thanks to those who have preceded me, for his communication. We well know that our President has the reputation of being a master in the foundry art, and after listening to his address, I can readily believe his record. I hope his year of office will be one of the most successful that the Institute has ever known.

Mr. W. Brooks: The desirability has been mentioned of the erection in this locality of a statue, or other memorial, to Dud Dudley. Four years ago it was suggested that ornamental iron gates should be erected at the entrance to Dudley Castle, as a memorial. Alderman Garratt, ex-Mayor of Dudley, thought that that would be a suitable monument. Personally, however, I should prefer to see a statue erected. But if anything is to be done I think this Institute will have to take the matter up on its own account. I should be very pleased to do anything I can to forward such a worthy object, and to remove the charge of neglect which now rests upon Staffordshire in this matter; and the earlier the subject is re-opened the greater will be the cause for gratification.

The Secretary announced the receipt of a telegram from Mr. Walter Jones, congratulating the President on his address.

The vote of thanks, proposed by the Chairman, having been put to the meeting and passed with acclamation,

The President replied upon the discussion as follows: I am much flattered to-night that Mr. Millard, who is one of the founders of this Institute, should have come to hear me, and I am also complimented that he should think the peroration of my address modest. North Countrymen do not generally obtain credit for being over-burdened with that virtue. I do not think it is any modest statement of the aims of this Institute that it should foster and increase the desire now existing in the iron-foundry trade for increased technical knowledge. I think that the iron and steel industries of Staffordshire have been having quite their full share of the benefits of the Institute, and I desired in my address and still wish to enter a plea for another important and rapidly extending district industry, and to suggest that the Institute would do well to directly encourage the foundry trade. Professor Turner, speaking as a University professor, has said this evening that he envies Edinburgh its magnificent Museum of Science and Art, and well he may. But he forgot to tell us that the whole of the cost of the Antiquarian Museum of which

I spoke, £70,000 was defrayed by the munificence of one private citizen of Edinburgh. Professor Turner's reference to the large pieces of ordnance at the Tower of London strengthens my own view that it is almost certain that cannon were cast on the Continent before the initial date in this country. As I mentioned in my address, Hogge, in the reign of Henry VIII., brought over Frenchmen to assist him, no doubt, in showing him a higher method of work than he had himself been accustomed to. France was evidently further advanced in this business at that period than we were. I am peculiarly gratified that Mr. Macfarlane should be able to tell us that foundry workmen are forming an increased number of the students in his technical classes. I think that that desire for technical information amongst the workmen is a spirit which is spreading. It is, too, a matter of the greatest possible hopefulness for the industry itself. I have maintained before to-day that our practical foundry workmen are unsurpassed by any country, either on the Continent or in America. Speaking from personal knowledge, I say that what these men cannot do cannot be done anywhere. Indeed, I have never professed myself able to equal many of them in practical work. The only thing I hoped to do was to surpass them in some technical knowledge, a line of thought and work which they never had opportunities of acquiring. Mr. Thomas has referred to the rule of thumb practice which still even to-day prevails in many foundries. That, unfortunately, is true, but I have reason to believe it is a diminishing quantity. Given further impulse in this same direction, I think, nay, I am sure, there is a great and growing future for the foundry industry of Great Britain. I have to thank you for your great kindness in listening to my address.

The second meeting of the Session was held at the Institute, Dudley, on Saturday, October 19, 1907.

The chair was occupied by the President, Mr. R. Buchanan.

Mr. Aubrey H. Granger was elected a member of the Institute.

Mr. George Hailstone read the following paper, which was illustrated by a number of lantern views :—

THE ACTION OF THE METALLOIDS ON,
AND THE
MICROSTRUCTURE OF FOUNDRY IRONS.

By GEORGE HAILSTONE.

In presenting the following paper to the Institute, written at the suggestion of its President, the writer wishes to point out the reason for dealing with the two subjects, "The action of the metalloids on foundry irons" and "The microstructure of foundry irons," is, that to thoroughly explain the one subject the other must be made use of. It also may be stated that the paper has been prepared from the foundryman's standpoint, and that the whole of the micrographs used to illustrate the paper have been prepared from the actual iron used or produced in a grey iron foundry.

The paper is divided for convenience under the two heads as above, and it was thought that it would not be out of place to give a description of the method adopted for the preparation of the samples for examination under the microscope, and the method of obtaining a permanent record of same.

When foundry or cast iron is in the liquid state it is considered to be a saturated solution of carbon, silicon, sulphur, phosphorus, and manganese in iron, the percentage of carbon generally present being between 3.0 and 3.5 per cent. The total amount of carbon varies with the quantity and effects of the other elements present, some of which increase and others diminish the total quantity. Chromium and manganese increase the solvent power of iron for carbon; silicon and aluminium act in the opposite direction, and therefore diminish it. For example, a ferrosilicon containing about 14 per cent. of silicon generally contains about 1.25 per cent. of carbon, practically all of which is in the graphitic form. However, it is very unusual to meet with foundry irons containing less than 2 per cent., or more than 4 per cent. of total carbon.

At one time carbon was supposed to exist in cast iron in only two forms, graphite as in grey iron, and combined carbon as in white iron. We are certain that carbon exists in grey iron as graphite, but the condition of the carbon in white iron is not thoroughly known. Probably some of the carbon exists as the carbide of iron, Fe_3 C., and some exists as a solid solution of carbon in iron, or may be that there are some lower carbides of iron dissolved in the iron.

The conditions of the carbon in cast iron at different temperatures are indicated by the curve, Figure 1. In the zone marked 1., above 1130 deg. centigrade, we have molten iron containing carbon in solution. In the zone 2. we still have carbon in the liquid solution, but some solid solution of carbon in iron, which is called "Martensite," containing 2 per cent of carbon, has crystallised out. In zone 3. we have the iron with some of the carbon in solution, but the rest has separated out as graphite. In the zone 4. we have martensite, or the solid solution of carbon in iron and graphite. If cast iron is kept for a long time at the temperature of this region, between 1000 deg. and 1130 deg. centigrade, the martensite becomes decomposed into ferrite and graphite, which is pure iron and pure carbon, but if sufficient time is not allowed the carbon will remain in solution as martensite. In the zone 5. we have martensite and cementite, with some graphite, if the graphite has once been formed in zone 4.; and iron and graphite if the carbon has been previously completely separated as graphite. In zone 6. we have a further change, pearlite being present, if sufficient time has been allowed for its formation at about 690 deg. centigrade, that is, at the line A.B., the martensite being decomposed into cementite and ferrite. As superfusion plays a part in the above-mentioned changes, we may get grey, ultra grey, mottled, or white cast iron from the same solution, according to the elements that are present. We have sulphur and manganese retarding the separation, and silicon stimulating the separation of graphite. The effects of temperature on a No. 3 iron containing 2.5 per cent of silicon, and a No. 1 iron containing about 3.5 per cent. of silicon may be stated thus :—

No. 3 Iron. Owing to the slow cooling and the presence of silicon in the zone 4. the change from martensite and graphite to martensite, cementite and graphite in the zone 5. is largely prevented. It is possible that silicon has the power of decomposing martensite in the zone 4., and this produces the stable condition of ferrite plus graphite. It may be suggested that silicon prevents super-cooling, and therefore assists in the separation of graphite.

No. 1 Iron. In the case of this iron the reactions referred to in the No. 3 iron are complete. The martensite is completely decomposed, silicon being present in a larger quantity, and the counteracting elements, manganese and sulphur, practically absent. The conditions of slow cooling in zone 4. have been extended, and the conversion of martensite and graphite to martensite, cementite, and graphite prevented. The stable condition of ferrite plus graphite has been attained.

The action of graphite on cast iron is to open the grain, weaken it, reduce shrinkage and chill, and indirectly soften it by being only mechanically mixed with it. Combined carbon closes the grain, increases the shrinkage and chill, and raises the strength.

Silicon. This element may exist in cast iron as a silicide of iron, but this silicide appears to be in solid solution in the iron, forming crystals of the cubic system. On examining a microsection of slowly-cooled iron containing 3 per cent of silicon and only traces of the other elements, excepting carbon, which was in a normal quantity, the writer has seen what is believed to be crystals of this solid solution, to which may be given the name of "silico-ferrite," side by side with crystals of normal ferrite.

The crystals of silico-ferrite are of a pale yellow colour, and the normal or ordinary ferrite white. It may be stated that the difference in colour is not due to any optical effect, as, on rotating the specimen on the stage of the microscope the colours remain unchanged, whereas, if the crystals were of the same composition the colours would have been reversed.

Silicon may be said to act in three ways in cast iron :—1. By inducing the separation of graphite in large flakes. 2. By inducing the separation of graphite in very fine flakes. 3. By uniting with iron and manganese to form silicides, which tend to induce a large crystalline structure, and also increase the hardness and brittleness in proportion to the amount of silicon present. Silicon does not appear to be able to unite with carbon at the ordinary furnace temperatures.

In foundry practice there is a definite limit for the silicon contents of a grey iron casting. It should not contain less than 0.8 per cent., or more than 3 per cent. of silicon. If it exceeds 3 per cent., then in thin castings the metal is apt to be overhard, and have a bright glossy fracture. On the other hand, when there is less than 0.8 per cent. of silicon, even the thickest castings are too hard and are apt to be quite white and brittle, and also incapable of being manipulated in the ordinary way. In Professor Turner's well-known experiments it is shown that the tensile strength of an iron is increased with every addition of silicon up to 2 per cent., and then the strength rapidly deteriorates with every increase of silicon. This is however only true with the certain iron that was experimented with. The writer has observed that with strong irons, prepared in the foundry for general use, the greatest strength is obtained with an iron containing from 1.25 to 1.50 per cent. of silicon. It may be taken as a fixed rule that the lower the silicon, the weaker will small castings be, and the stronger the large castings; the higher the silicon in a small casting, up to 3 per cent., the stronger it will be, and the weaker the large casting.

The general effect of silicon upon cast iron is to increase the hardness, but as it induces the separation of graphite it acts indirectly as a softener. It also lessens shrinkage. By combining with any oxygen present it prevents blowholes. It increases the tenacity, but decreases the ductility.

Manganese. The condition of carbon in cast iron being influenced by manganese is most likely partly due to its having the power to combine with carbon on its own account, therefore to increase the quantity of combined carbon in the iron. It also has an affinity for silicon and sulphur, which form manganese silicide and manganese sulphide respectively, when the manganese is present in the quantity usually present in cast iron.

Manganese prevents the oxidation of iron when in the molten state; it also reduces any oxide that may be present in the iron, being itself more readily oxidised, and passing into the slag as manganese silicate, hence the practice of allowing the white hot iron tapped from a cupola to stand for a time in the ladle before casting. The slag forming tendency of manganese tends to produce basic slags, which are most favourable for the elimination of sulphur, for the more basic the slag the more completely will sulphur be removed. Manganese increases the shrinkage of cast iron, and Keep has shown that an increase of 1.0 per cent. of manganese, over the normal quantity usually present, will increase the shrinkage 26 per cent. In all probability this is due to the manganese retaining the carbon in the combined form. Manganese increases the hardness of cast iron enormously, this being advantageous in producing a hard chill. The physical properties of cast iron are not materially affected as long as the manganese present does not exceed 1.0 per cent. The most general amount present in cast iron is from 0.3 to 0.7 per cent.

To sum up, the effects of manganese on cast iron are, to cause the carbon to remain in the combined form, and therefore increase the hardness and shrinkage; to prevent blowholes, by combination with any oxygen present; to produce a hard chill; to unite with sulphur, and in this respect decrease the hardness; to form a basic slag, and thus partly remove the sulphur and phosphorus; to produce a close grain, and, therefore a strong casting, and to increase the transverse strength.

Sulphur. This element is not usually present in grey iron castings above 0.13 per cent., but when present, even in very small quantities, it exerts a very considerable influence on the properties of cast iron. Sulphur generally exists in the iron as a sulphide, and when manganese is present, which is nearly always the case with foundry irons, as manganese sulphide, having the formula Mn S. When these elements occur in atomic proportions they completely neutralise each other; on the other hand if either is in excess they form manganese carbide or ferrous sulphide as the case may be. Iron sulphide being readily fusible, and also decomposing at high temperatures, a large proportion of the sulphur escapes as a gaseous compound, giving the metal a spongy texture. As above stated, when manganese is present the sulphur appears to unite with it in preference to iron, and as manganese sulphide has a high melting point, and also a high dissociation point, the sulphur is not then liberated in the gaseous form, so that blowholes and red shortness are to a certain extent avoided.

In making micrographic analyses of cast iron, the writer has observed that when the sulphur has been below 0.11 per cent., the manganese sulphide has always been found in the carbide of iron or cementite, but when the sulphur has been found to be above 0.11 per cent., some of the manganese sulphide is found in the pearlite.

The tendency of sulphur is to neutralise silicon. It acts in a similar way to manganese in keeping the carbon in the combined form. Sulphur generally increases in iron as silicon diminishes. As sulphur exists in cast iron, when there is not enough manganese present to neutralise it, as a moderately fusible sulphide, it is liable to remain in the liquid form after the mass of metal has become solid, and tends to segregate in the middle and upper parts of a cooling casting.

The quantity of sulphur that may be allowed in a casting entirely depends upon the silicon present, and for a soft casting should not exceed 0.07 per cent. In strong castings, such as cylinders, it has been found that to have about 0.11 per cent. of sulphur present, the greatest wearing properties are obtained, the injurious effect on the strength being amply compensated by the additional wearing properties the casting will have.

The general effects of sulphur on foundry irons are :—It makes iron more fusible and liquid by the formation of a fusible sulphide; as sulphur tends to the formation of combined carbon, the iron is harder and the shrinkage is increased; with much sulphur, and the absence of manganese, and a high casting temperature, sulphur causes blowholes; because of combined carbon sulphury irons produce a deep chill; as segregation occurs, and blowholes and fusible sulphides are formed, all of which produce intercrystalline weaknesses, sulphur tends to diminish the strength of cast iron.

Phosphorus. This element exists in foundry irons as a fusible phosphide having the formula Fe_3P., which contains 15 per cent. of phosphorus. Practically the whole of the phosphorus in an ore charged into the blast furnace passes into the metal produced. Phosphorus has little direct influence on the condition of the carbon in cast iron. Phosphide of iron is very hard, but not so hard as carbide of iron. It is found associated with the carbide of iron or cementite. On examining an iron containing phosphorus under the microscope, the phosphorus compound is found in the cementite in the form of streaks and dots.

Phosphorus increases the fluidity of cast iron considerably, hence the use of highly phosphoric iron for fine castings, where the strength is only a secondary consideration. As the phosphide of iron, having a freezing point of about 900 deg. centigrade, remains fluid after the main bulk of the iron has solidified, an excess seems to have a mechanical influence upon the cementite, by causing it to run in nearly straight lines throughout the casting, thus forming lines of weakness and therefore making the iron more brittle and more easily fractured under impact.

The presence of phosphorus lowers the percentage of total carbon, and this effect increases proportionally with the increase of phosphorus. With 2 per cent. of phosphorus in pure cast iron there is not more than 2 per cent. of carbon.

For strong castings, phosphorus should not exceed 0.6 per cent., and when the amount exceeds 1.5 per cent. the iron becomes very weak and hard.

To sum up briefly, the effect of phosphorus on cast iron is to make the metal harder, more fusible, whiter, more fluid and weak; it prevents blowholes and lessens shrinkage.

THE MICROSTRUCTURE OF FOUNDRY IRONS.

As a section of iron to be examined micrographically needs special preparation, perhaps it will be as well to explain the method used in obtaining the micrographs used in this paper, before dealing with them.

The samples of cast or pig iron as the case may be, are either cut in a lathe, or by filing in a vice, or by other means according to circumstances, to a suitable size. A very convenient sized section is one about 0.5in. in diameter and 0.1in. thick.

The face of the section to be examined is filed flat with a dead smooth file, and the edges slightly bevelled to prevent it injuring the polishing pads. When all the file marks are running in the same direction the section is rubbed at right angles to the file marks on a piece of F F emery cloth, that has been stretched upon a piece of smooth hard wood, a convenient size being 12in. by 3in. by 1in. Again, when all the marks made by the F F emery cloth are in the same direction, and the whole of the file marks have been removed, the section is reversed and rubbed on O emery cloth, and this process is continued on O,OO,OOO and OOOO emery papers, reversing the section each time the paper is changed.

The section of iron is then rubbed, at right angles to the scratches, on a piece of wash leather, covered with the finest rouge, stretched on a piece of wood, until the section is free from scratches.

In order to develop the structure of cast iron, the polished surface of the section is subjected to the action of various re-agents, such as dilute nitric acid, iodine solution, and 5 per cent. solution of picric acid in alcohol, to reveal the various constituents.

The method adopted by the writer is as follows :—The polished surface about to be examined is rubbed on parchment stretched upon a piece of sheet glass, which has been previously moistened with a 5 per cent. solution of iodine in alcohol, for two or three minutes.

The section is then washed with a few drops of alcohol, and then gently warmed to dry. It is then finally rubbed a few times very lightly on the rouged wash leather pad again. The specimen, with the exception of mounting, is now ready for examination by the microscope.

It often happens that the sections of iron are not regular in shape, and the polished surface is not parallel with the opposite sides. As the preparation of pieces of regular thickness involve the loss of time, as in the case of a piece of white iron, and also as it is generally only one flat surface that is required, it is necessary to mount the irregular shapes of metal on the glass microscopical slide so that the polished surface of the section is always parallel with that of the microscopic slide.

The most convenient way to do this is to have a number of pieces of metal tube about 1in. in diameter, cut off perfectly true, about 0.25, 0.50, 0.75 and 1in. long respectively. The metal section is placed face downwards upon the rouge pad, and the nearest sized ring placed over it.

A piece of plastic material, such as plasticine, is pressed upon the centre of a microscopic slide, to which it adheres. The slide is then turned down, and is pressed on to the back of the specimen until the glass rests upon the top of the metal ring; the slide is then removed with the section adhering to it, having its polished surface parallel with that of the slide.

The whole of the operation of mounting in this way takes about 5 seconds to complete. After examination, the section of metal may be removed most readily, and further treated if necessary.

Any good microscope stand may be used, but it is desirable that it should be fitted with an inclining joint so that it may be used in both horizontal and vertical positions, and it should have a rough adjustment, also a sensitive fine adjustment. The base should be sufficiently large and weighty to render the instrument perfectly rigid in both positions.

Metallic sections, being opaque, cannot be examined by transmitted light, consequently special illuminating apparatus has to be used. The illumination used for all the sections shown is vertical. This is produced by having a hole in the microscope tube, just above the objective, and a right-angled prism placed in it in such a position that it reflects any light which passes on to it, through the hole, down on to the section, which is then transmitted up the tube of the microscope. A Welsbach gas burner may be used as a source of illumination for both examination and photographing. Between the source of light and the prism illuminator a bull's-eye condenser should be placed to concentrate the rays.

There are many forms of cameras made for micro-photography, some working in horizontal and others in vertical positions. The camera with which all the micrographs that follow were taken was of the horizontal type.

In taking a photograph, the object should be first carefully focussed under the microscope in the ordinary way, and without removing the eyepiece, the hood of the camera pushed over the latter, and the camera extended to give the required magnification.

The final focussing is best done on a piece of plain glass in the place of the ordinary ground glass camera screen, and, an ordinary pocket lens being placed on the centre of the glass, the fine adjustment screw is turned until a very distinct image of the object is seen. The glass screen is then replaced by a dark slide containing an ordinary photographic dry plate, the slide drawn and the exposure made.

The time of exposure depends upon the magnification required, the source of illumination, and to a great extent upon the object. For an ordinary grey cast iron, with a magnification of 250 diameters, the source of illumination being an incandescent burner, the exposure required is about 20 minutes. A magnification of 50 diameters requires about 10 minutes under the same conditions. The photographic plate after being exposed is developed in the ordinary way.

Having described the method of preparing a section for examination by the microscope, also the method of obtaining a permanent record of same, the micro-constituents of foundry irons will be described, and it will be shown how they occur in pig iron and finished castings.

There are six micro-constituents generally observed in grey foundry irons, viz. :—Ferrite, cementite, pearlite, graphite, phosphide of iron or phosphorus eutectic, and manganese sulphide.

Ferrite is pure iron, sometimes it occurs in crystals that are readily recognised, but more often than not as a white groundwork or matrix. Being unstained by the etching liquid that is used to reveal the various constituents, it remains white. Silicon and manganese are present in the ferrite, and as they are isomorphous with the iron they often replace some of the crystals of ferrite. Ferrite is the softest constituent of cast iron, excepting graphite. The micrograph No. 1 shows crystals of ferrite, through which runs a very large flake of graphite.

Cementite is a chemical compound of carbon and iron containing 6.6 per cent. of carbon and corresponding to the formula $Fe_3 C$. The iron is sometimes replaced in this constituent by the other metals associated with the iron. For instance, we get double carbides of iron and manganese. Cementite is the hardest constituent of cast irons. It resembles ferrite inasmuch as it is not stained by the etching liquid, but being very hard it stands up in relief after polishing, and is therefore readily distinguished. Micrograph No. 2 clearly shows a portion of an area of cementite. The black portions in the cementite being the phosphorus compound.

Pearlite is a definite mixture of ferrite and cementite. Pearlite contains 0.89 per cent. of carbon or 13 per cent. of cementite. Its typical formula is $21\ Fe + Fe_3\ C$. The carbon in pearlite is molecularly associated with only about 12 per cent. of the iron, 87 per cent. of the latter being in the free state. Pearlite is recognised by its characteristic striated structure, consisting of alternate laminæ of ferrite and cementite. It is coloured dark by the etching liquid, and when the specimen is a good one it has a very beautiful mother-of-pearl appearance.

As ferrite and cementite when in segregated patches are not coloured by the etching liquid, the question may arise, how is it that pearlite is? The explanation of this may be that, on polishing, as the cementite is the harder constituent, the ferrite is rubbed away much more easily, and therefore the cementite stands up in relief. When the etching liquid is put upon the specimen, some of it falls into the recesses formed by the rubbing away of the ferrite and is not completely removed in the final polishing, also as cementite stands up above the ferrite, shadows are formed, and therefore we get this peculiar striated appearance. Micrograph No. 3 shows the structure of pearlite, the light portion being the cementite and the dark portion the ferrite.

Graphite is practically pure carbon in the free state; it occurs in cast iron in varying sized flakes, from very large to very small. Micrograph No. 4 shows large and small flakes of graphite in a matrix of ferrite.

The phosphorus compound was shown in micrograph No. 2., its composition corresponding to the formula $Fe_3\ P$. It is always found associated with the cementite, with which it forms a eutectic, and is characterised by the form it takes, like so many streaks and dots.

Manganese sulphide occurs in square or oblong shaped crystals of a " dove " grey colour. It sometimes occurs in the cementite and sometimes in the pearlite, according to the amount of sulphur present. Micrograph No. 5 shows two crystals of manganese sulphide with a matrix of pearlite. Manganese sulphide corresponds to the formula of MnS.

The next three micrographs show the difference in structure of I X L pig iron Nos. 1, 3, and 6.

Micrograph No. 6 shows the No. 1 iron. It will be seen that the structure of this iron consists of large flakes of graphite in a matrix of crystals of ferrite. The chemical analysis of this iron is, graphite 3.27 per cent., comb. carbon 0.050 per cent., silicon 3.25 per cent., sulphur 0.045 per cent., phosphorus 0.40 per cent., manganese 0.78 per cent.

Micrograph No. 7 is a section of the No. 3 iron. It will be readily seen here that the flakes of graphite are much smaller and thinner than in the previous section, also that there is an area of cementite in the centre of the section, the main ground-work or matrix still being ferrite. The chemical composition of this iron is as follows:—Graphite 3.130 per cent., combined carbon 0.25 per cent., silicon 2.35 per cent., sulphur 0.058 per cent., phosphorus 0.40 per cent., manganese 0.75 per cent.

Micrograph No. 8 gives the structure of the No. 6 iron. It will be seen that the structure of this iron is entirely different from the Nos. 1 and 3, consisting of small thin flakes of graphite, in a matrix of pearlite, in which there is an area of cementite. The composition of this iron is:—Graphite 2.25 per cent., combined carbon 0.75 per cent., silicon 1.580 per cent., sulphur 0.100 per cent., phosphorus 0.39 per cent., and manganese 0.75 per cent.

Micrograph No. 9 is a section of Seaton Carew Hematite, containing the following:—Graphite 3.125 per cent., combined carbon 0.338 per cent., silicon 1.076 per cent., sulphur 0.057 per cent., phosphorus trace, manganese 0.874 per cent. In this section the graphite, cementite, and pearlite are very intimately associated with each other. The appearance of the structure of this iron shows it to be a strong iron.

Micrograph No. 10 is a section of Clay Cross pig iron No. 4, containing silicon 1.332 per cent., sulphur 0.069 per cent., phosphorus 1.501 per cent. Here the graphite is in very small flakes in a matrix of ferrite, in which is intermixed areas of cementite containing the phosphorus eutectic. The appearance of this structure denotes that this iron is of a weak brittle nature.

Micrograph No. 11 is a section of Bestwood siliceous pig iron, containing graphite 3.860 per cent., combined carbon trace, silicon 4.359 per cent., sulphur 0.030 per cent., phosphorus 1.122 per cent., and manganese 0.372 per cent. Here we find long flakes of graphite in a matrix of ferrite, intermixed with areas of the phosphorus compound. This iron is very weak, owing to the large percentage of graphite and silicon.

This ends the micrographs of pig irons; the following micrographs are of sections from castings.

Micrograph No. 12 is a section from a very light casting containing:—Graphite 3.103 per cent., combined carbon 0.216 per cent., silicon 2.693 per cent., sulphur 0.068 per cent., phosphorus 1.020 per cent., manganese 0.610 per cent. The light portions of the section being the cementite, and the dark portions graphite and pearlite.

Micrograph No. 13 is a section from a casting containing:—Graphite 2.400 per cent., combined carbon 0.586 per cent., silicon 2.316 per cent., sulphur 0.123 per cent., phosphorus 0.960 per cent., manganese 0.356 per cent. A transverse test bar cast from this metal, 2in. by 1in. by 3ft. centres, broke at 34cwt. with a deflection of ⅝in. It will be seen that in this section the graphite is in very small flakes in a matrix of ferrite and pearlite, also that the areas of cementite are very small.

Micrograph No. 14 is from a medium sized soft casting, the composition of it being:—Graphite 2.500 per cent., combined carbon 0.589 per cent., silicon 2.167 per cent., sulphur 0.123 per cent., phosphorus 1.150 per cent., manganese 0.533 per cent. This section shows clearly medium sized flakes of graphite, which is really in a matrix of pearlite, but the section has been polished well to bring out the flakes of graphite.

Micrograph No. 15 is a section from a strong casting. The transverse strength on the 2in. by 1in. bar gave 37cwt., with a deflection of ½in. The composition of this iron is:—Graphite 2.630 per cent., combined carbon 0.583 per cent., silicon 1.547 per cent., sulphur 0.117 per cent., phosphorus 0.768 per cent., manganese 0.497 per cent. Here the graphite, cementite and pearlite are very intimately mixed; this is an ideal structure of a strong iron.

Micrograph No. 16 is of a high phosphorus iron, also fairly high in silicon. This metal is good for casting a large bulk of metal, where strength is only of a secondary consideration, the high phosphorus giving it a low casting temperature and the silicon promoting the formation of graphite; thus sinking is overcome. The composition of this iron is :—Graphite 2.500 per cent., combined carbon 0.291 per cent., silicon 2.549 per cent., sulphur 0.062 per cent., phosphorus 1.895 per cent., manganese 0.642 per cent. The microstructure shows that graphite and ferrite are in the matrix, the white portion being the phosphide of iron.

Micrograph No. 17 is a section from a heavy wheel containing graphite 2.720 per cent., combined carbon 0.422 per cent., silicon 1.478 per cent., sulphur 0.071 per cent., phosphorus 1.335 per cent., manganese 0.591 per cent. This section shows very clearly the graphite, pearlite, cementite, and phosphorus eutectic.

Micrograph No. 18 shows the effect of using an iron too high in silicon for a large casting. The flakes of graphite being too large, also there are large crystals of ferrite, the boundaries of which form lines of weakness. This iron is of the same analysis as micrograph No. 13, which has been used for the right sized casting.

Micrograph No. 19 is of a section of cast iron from an old annealing pot, which has been burnt. All the graphite has been oxidised. This iron is full of cracks containing oxide of iron, thus it can be readily seen that it is useless to use up in the cupola again.

From the foregoing remarks I think you will agree with me how absolutely necessary it is that the modern foundry manager who wishes to attain the greatest possible measure of success, by the avoidance of the production of unsuitable castings required for various purposes, should have some knowledge of the chemical and microscopical constituents that enter into the composition of the various irons used in his mixtures, not relying as many founders do, at the present time, on the old-fashioned, time-honoured, but oft misleading judgment by " fracture."

THE DISCUSSION.

Mr. J. **Ernst Fletcher** : We have had a paper which should give everyone engaged in foundry practice a greater interest in their work, and a desire to know more about the pros and cons of their trade. Mr. Hailstone is very much to be commended for bringing before us what I may term this combined paper, showing as it does the action of metalloids upon cast iron, as well as the microstructure of the same. The two, as he truly intimates, are quite inseparable. I think the time is coming when we in this country will be obliged to take up the study of foundry irons in the thorough and scientific manner in which it has been brought before us to-night. If one goes into France, Germany, or Belgium and converses with foundrymen, it will be found, almost without exception, that those men are possessed of much of the information contained in the paper. That being so, there is no wonder that our competitors abroad are successful. When we consider that those abroad have to deal with inferior irons compared with ours, we feel bound to compliment them upon their results. The time is coming when we shall have to use very much inferior ores to those we have at present. The old method of judgment by fracture will have to be superseded by a knowledge of chemistry and micrography, and ironfounders will have to know as much as the steel makers of the scientific side of their business. There are several points in the paper that appeal to me. One of them is on Page 26 in connection with silicon. Mr. Hailstone says :—"This element may exist in cast iron as a silicide of iron, but this silicide appears to be in solid solution in the iron, forming crystals of the cubic system." Having had some experience in the examination of various silicon irons and alloys, I can corroborate what Mr. Hailstone has said here—that this yellow silicide of iron is very often visibly present in cast iron. I have one or two micrographs with me which, as can be seen, show up the exact form of these crystals of silicide of iron, which can only dimly be seen in the microscopic sections of so low percentages as 3 per cent. of silicon. There are other points, but I do not wish to touch upon these now, because I hope shortly to have the pleasure of saying something myself about the influence of various gases on the structure of cast iron and steel, and that to some extent has reference to two or three of the matters mentioned by Mr. Hailstone. I hope we shall not be behindhand in this district in picking up, as students, the best methods of the examination of cast iron. The paper should stand almost as an outline text-book for every founder present.

Mr. **Geo. H. Head** : I have not had time to look through the paper until this evening, but I congratulate Mr. Hailstone upon the excellent way in which he has brought the subject before us. Mr. Hailstone closes his paper as follows :—" From the foregoing remarks I think you will agree with me how absolutely necessary it is that the modern foundry manager who wishes to attain the greatest possible measure of success, by the avoidance of the production of unsuitable castings, required for various purposes, should have some knowledge of the chemical and microscopical constituents that enter into the composition of various irons used in his mixtures, not relying, as many founders do at the present time, on the old-fashioned, time-honoured, but oft-misleading, judgment by 'fracture.'" As regards this closing paragraph of the paper, I think the President will remember an occasion some time ago at Tipton, when the question of judging iron by fracture came very forcibly to the front. I myself, since then, have known cases in which founders have ordered the wrong iron through judging by fracture only. Manufacturers ought to bring themselves up to date, and not stick to old-fashioned methods too closely. There is no excuse for the rising generation to remain ignorant of the scientific knowledge affecting their industries. There are cheap technical classes, and the University of Birmingham is close, too. On Page 34, with regard to micrograph No. 9, Mr. Hailstone tells us the name of the pig iron, of which he has given us the analysis (Seaton Carew), but I don't think he mentions the names of the irons up to No. 9. It might have been an advantage to have had the names of all, so as to make the paper more complete. I am sure he has taken a large amount of trouble in handing us all these analyses, because he has given them so minutely.

Mr. W. KENDRICK : I think we must congratulate ourselves as foundrymen upon the way our interests are represented. Our President has, in his recent Presidential Address to this Institute, dealt with this subject, and the first paper we have had this session has been by a foundryman. I agree that it is quite impossible to produce from hard iron, castings and then expect them to machine all right. What Professor Turner has already ascertained about silicon is fully borne out in Mr. Hailstone's paper. As to sulphur, I have hitherto thought there was not a good word to be said for sulphur in cast iron, and it is, as you know, one of the worst elements that we have to deal with in pig iron or cast iron, but I frequently think that the trouble is more often than not due to the coke that we get, and if foundry managers would be careful with regard to getting good coke, even if it cost more money, they would avoid much trouble. This is a very practical paper, and it is presented in a manner which enables it to be well understood by those who have not much time to give to the study of the chemistry of iron, and I, for one, have thoroughly enjoyed the paper.

Mr. J. E. FLETCHER : There is one point I omitted in my previous remarks. Mr. Hailstone has not mentioned whether in the micrographs the size of the sections has been uniform—I mean the sections of the castings from which the protographs have been prepared. If pieces for examination are being taken from castings the test pieces attached to such castings should be all of the same section, and cast as nearly as possible at the same temperature. This is important if correct comparisons are to be made and reliable results obtained.

The **President**: I have listened with considerable attention and interest to Mr. Hailstone's excellent paper, and I may say that I have somewhat of a fatherly interest in the matter, as Mr. Hailstone was a colleague of mine several years ago, and we worked together, so as to produce the best results possible. As regards Mr. Hailstone's experience of the metallography of foundry irons, I can assure you it is very extensive indeed. I can bear out Mr. Hailstone's remarks as to the great improvement attending these matters in recent years, for whilst anaylsis and metallography are certainly largely used on the Continent, yet these are certainly not unknown subjects in this country either, and they are used in workshops in this district. We must give due credit to business men at the head of the great iron industries in this country, and we must admit that they have their eyes as open as their competitors have, for any methods or ideas by which they can improve or cheapen their products. I may mention that I believe I was the means of Mr. Hailstone entering his present employment, which is a case in point, for it was only necessary to mention to the Managing Director of that business how great an advantage it would be to the foundry work to start a laboratory for him to take up the idea readily; and he has found that the foundry laboratory is a good paying investment. When such a laboratory has a young man of attainments at the head of it, like Mr. Hailstone, it is an excellent adjunct to the iron trade. With regard to the paper itself, I am rather afraid that Mr. Hailstone does not expect any criticism from me, and I have hardly any desire to criticise. On Page 27 there occurs the following passage: "In Professor Turner's well-known experiments it is shown that the tensile strength of an iron is increased with every addition of silicon upon to 2 per cent., and then the strength rapidly deteriorates with every increase of silicon. This is, however, only true with the certain iron that was experimented with. The writer has observed that with strong irons, prepared in the foundry for general use, the greatest strength is obtained with an iron containing from 1.25 to 1.50 per cent. of silicon." It is worthy of note that Professor Turner, in making his great experiments, conducted them by synthesis. He took Swedish iron (I believe), and he got the silicon into the iron by means of sand. He had iron, sand, and carbon, and I think his test bars were ½in. square; so, in the very matter of size alone, you get a distinct difference between the test bars used by Professor Turner and those which we use in foundries. As to the sulphur, carbon, and manganese, I don't know how much those elements affect our foundry test bars as compared with the manner in which they affected Professor Turner's test bars, in which these elements were practically absent. There is one point which Mr. Hailstone does not seem to have brought out, and that is the enormous difference silicon makes in casting. The softness of light castings can be made practically similar to the softness of heavy castings, but the effect in each case is obtained by different percentages of silicon. Then we have also to consider how slow or fast cooling affects the carbon. I think more attention is necessary to this question of time—of slow or fast cooling causing the differences required in the percentages of silicon used, to get a definite effect in softness. I know a foundry where they were making a lot of white castings when they wanted them grey, and one of the members of the firm said, " We will fill our cupola with white scrap iron and white castings, and they added some iron high in manganese in the cupola, and the iron came out grey. They asked me to explain it, and I said that the manganese used neutralised the sulphur. So that manganese became a very distinct softening agent on that occasion. Manganese in excess (if sulphur is not in excess) may harden, but my experience of grey iron castings is that I have hardly ever known manganese to harden them. If you want a good deflection on your test bars, don't have your manganese high. If you do, they will be stiff, and you won't get your deflection.

Mr. Hailstone : I am glad Mr. Fletcher has seen the same thing as myself with regard to silicide. Some experimenters don't seem to have come across that phenomenon, or at any rate they don't appear to have mentioned it. With regard to the size of the sections, if all the irons were cast in test bars you would then get varying structures. A man must make his own standards from the particular irons he uses, those irons not suiting everybody. As to the slides, in Nos. 1 to 6 I brought these before you to show how the different constituents occurred in foundry irons; most are from castings, but one is from a siliceous iron. Regarding the sulphur question, 0.11 per cent. sulphur is not considered very high, in fact, it is an advantage, especially in cylinders, but if you get above that, that is, manganese sulphide in the pearlite, your castings are weakened. Regarding the combined effects of slow cooling and silicon on iron, well, if I had gone into that matter I should have had to have written another paper. Many people say you cannot get a grey iron without silicon being present. To show the effects of slow cooling, some months ago I got a sample of a pure steel, containing only one one-hundredth of a per cent. of silicon and .009 phosphorus; I melted that with carbon in a carbon crucible, and kept it for two or three hours at a temperature of 1,130 deg. cent., then allowed it to cool slowly. That iron contained on analysis 4.311 of graphite, and only a trace of combined carbon, so that that iron contained theoretically the amount of carbon that pure cast iron contains as graphite without silicon being present. The reason why you use a high silicon in a light casting, and a low silicon in a heavy casting, is because the time helps the silicon. In a large casting it takes several hours, or days, to cool, and taking into consideration the time, you find that assists in the formation of graphite the same as silicon, as before stated. In a very small casting, it probably only takes 1 or 1½ hours to cool, therefore you must have a larger amount of silicon there to promote the formation of the graphite, otherwise you will get shrinking and drawing in the casting. As to manganese, we rarely get manganese above .7 per cent. in foundry mixtures, therefore the metal would not appear hard. If you had 1½ or 2 per cent. of manganese in your mixture, you could not drill the resulting metal, providing sulphur was normal. Mr. Buchanan also spoke about adding manganese to cast iron which had been coming out white, to make it grey again. Well, I think I pointed out in my paper that the manganese neutralised the sulphur, and then sulphur neutralises manganese. Regarding oxides, of course everyone can have an opinion about that, but I don't see how it is to be proved, because the moment you begin to try to estimate the amount of oxygen in cast iron you are landed in difficulties, and the more you go into it the more difficult does the matter become.

The PRESIDENT : We have had an excellent paper from a clever young metallurgist who knows his subject thoroughly well. He had several years at Birmingham University; and, since then, several years in workshop practice. It does him the greatest credit, and I will pay him the compliment of hoping to see him here again another time.

On the proposition of Mr. JAMES PIPER, a hearty vote of thanks was accorded to Mr. Hailstone by acclamation.

Mr. HAILSTONE, in responding to the vote of thanks, observed that a paper which he had originally thought of bringing before the Institute could not be got ready in time, so perhaps he might be able to give them that one on some future occasion.

The third meeting of the Session was held at the Institute, Dudley, on Saturday, November 23rd.

The President (Mr. Robert Buchanan) presided.

The minutes of the previous meeting were read, approved, and signed.

Messrs. James Beard, John Parker, H. C. Parkes, and H. T. Pinnock were elected members of the Institute.

The Secretary announced the death of Mr. George Williams, of Ashton-under-Lyne, an old and valued member of the Institute.

Mr. J. Ernst Fletcher then read the following paper :—

THE INFLUENCE OF GASES ON THE STRUCTURE OF CAST IRON AND STEEL.

By J. ERNST FLETCHER.

In the paper read by M. Henri Harmet, of St. Etienne, at the Dusseldorf meeting of the Iron and Steel Institute on the "Compression of Steel Ingots by Wire-drawing," that gentleman advanced a theory in explanation of the behaviour of steel whilst cooling and solidifying in the ingot mould.

It will be remembered that the diagram Fig. 1 was used to illustrate how the envelope, *a.a.a.*, frozen by contact with the ingot mould *b*, is fixed as far as its external dimensions are concerned, and, as a vase, whose walls are gradually thickening, contains the liquid steel. The formation of the "pipe" was explained by the theory that imaginary bars assumed to pass through the axis of the ingot are, during cooling, fissured and fractured by contraction at their centre; that such fissures or cracks occur when the centre of the ingot is in a pasty condition, the walls of the ingot being then solid and fixed in position; and that the liquid in the vase immediately above the recently fissured interior fills and more or less welds together the cracked central mass, and hence it follows that, as the liquid descends to fill up the fissures and cavities in the ingot centre, a "pipe" results in the upper portion of the ingot.

It will, however, be interesting to follow the gradual congelation of the metal as it fills the ingot mould and afterwards. In this way it is possible to define the shape of the vase at all stages of its growth in thickness, and to arrive at the approximate contour of the "pipe" or central cavity in the ingot when cold. In Fig. 2 the filling of the mould layer by layer is indicated by the horizontal lines 1, 2, 3, 4, etc., whilst the successive freezing of each layer is shown by the curved lines *a*, *b*, *c*, *d*, etc.; the portion which retains the last liquid to solidify has the form and position indicated in black.

Figs. 3, 4, 5, and 6 show the influence of shape of mould on that of the "pipe."

It is obvious that the rate and manner of cooling must have considerable effect on the shape as well as on the dimension of the "pipe," as a study of Figs. 7, 8, and 10 will show.

Thus in Fig. 7 the lower part of the ingot is cooled slowly, and the top rapidly. In Fig. 8 the upper and lower portions are cooled slowly, the centre quickly, and in Fig. 10 the lower portion is cooled quickly, and the upper slowly. The action of such differential cooling as illustrated in Figs. 7 and 10 can be still further demonstrated by supposing the mould to be constructed of two portions, one of thick rapidly cooled metal, and the other of heated sand or composition.

In the study of Fig. 11 one can readily see that the effect of chilling the lower portion of the ingot is to bring about the raising of the central liquid mass by the compression of the quickly contracting envelope contained within the chill. Such an arrangement obviously diminishes the volume of the "pipe," and is commonly used for this purpose.

It is necessary to go much further, however, for though it is undoubtedly interesting and instructive to follow the progress of the freezing of the ingot envelope, and therefore to define beforehand the approximate form and location of the "pipe," it is still more valuable to trace the gases, which, in escaping from the gradually solidifying ingot walls, find their way to the central zone of liquid through which they ascend, and, unless imprisoned, escape into the atmosphere.

The common "closed-top" ingot is an illustration of imprisoned gases forming under the conditions of congelation shown in Fig. 13, and the sphere cast in a chill (Fig. 5) is another.

Steel, Iron, and all other metals converted from the solid to the liquid state by the application of heat contain, when liquid, gases in solution to a greater or lesser extent. These gases are driven out more or less completely when the liquid metal passes to the solid condition. Three aids to such gas escape are used in practice, viz. :—(1) Rapid chilling, which by causing molecular contraction, prevents the inclusion of gas bubbles between adjacent crystals; (2) very slow cooling of the liquid mass whereby the gases can rise to the surface, and thus leave a gas-free liquid; (3) rapid chilling, aided by compression, which again brings the adjacent crystals of the solidifying mass into such close contact *that gas inclusion* is impossible.

RAPID CHILLING.

When the hot liquid steel impinges against the cold thick walls of an ingot mould the solidifying envelope ejects the gases it contains, the bubbles thus ejected being driven inwards through the still liquid interior.

Fig. 14 shows at (*a*) a gas bubble in the "just-freezing envelope" of a steel ingot. As the steel solidifies the bubble is driven inwards by the gradually thickening and contracting metal in its rear. Its original spherical form becomes "pear" shaped, and more and more elongated by the resistance of the pasty mass through which it may have to pass before reaching the more liquid interior where it can ascend and escape; *b*, *c*, and *d* show such elongated bubbles.

From the examination of ingots of low "Brinnell" type it is found that when gas bubbles are imprisoned under the skin, those nearest the outside of the ingot are much smaller than such as are more deeply seated, the explanation being that at the chill surface a number of small gas bubbles start off on their journey towards the liquid centre and coalesce after travelling some distance—such distance depending on the fluidity and corresponding resistance of the steel through which they are being driven. If the cooling is slow, and the steel very hot when poured, then the likelihoods are that most of the gas bubbles will reach the ingot centre, and there help to form the "pipe."

Fig. 15 and Fig. 21 photo show clearly a number of such gas streams imprisoned in the solid steel before reaching the ingot centre.

It is plain that the gas bubbles are driven off normally to the chilling surface, and move in paths normal to the ingot mould face as long as the chilling or solidifying effect of such chill surfaces is sufficiently powerful. Theoretically, therefore, in a spherical mould sufficiently massive to bring about instantaneous solidification, the gas cavity would be a sphere located in the exact centre of the ingot mass. The gas paths followed during the cooling of cylindrical and square ingots are shown in Figs. 16 and 17.

The gas bubbles thrown off from the ingot mould sides and bottom coalesce, and in thick streams traverse paths which are approximately the surfaces of the cone or pyramid, the final exit of the gases being, of course, along the axis of the ingot. The point "o" is the lowest possible limit of the central "pipe."

In square or polygonal ingots it follows that between each pair of adjacent faces the bisecting plane is the path by which gas bubbles expelled normally to such faces escape to the central zone of the ingot mass; they are planes of weakness, and, as is well known, it is along these planes that cracking during cooling generally occurs.

It might, therefore, be safely argued that rapid chilling of an ingot, by rapidly driving inwards the gas bubbles, is a means of confining ingot gases within the limits of the central " pipe."

Mr. Eaton Shore, of Rugby, has made practical use of this fact; by casting his " Eatonia " bronzes in very thin metal moulds immersed in a bath of cold water, he is able to secure sound " pipeless " castings. The study of gas-exit and its relation to the microstructure of metals is very plainly shown in connection with cast iron.

The fracture of a mottled iron ingot " chill-cast " shows clearly the gas paths and the position of the " pipe," Fig. 20.

A similarly cast ingot of white iron when fractured revealed the imprisoned gas bubbles, the gas paths and zones of weakness (Figure 21). Further, it is possible to prove that the crystalline structure of a cast ingot is determined by the direction of the gas paths, as will be seen by reference to micro-photographs 22 to 26.

The iron " fir-tree " crystals, first to solidify, have their major axes or trunks parallel to the direction of the gas streams, and the eutectic freezing afterwards also takes the same direction of orientation. It is not difficult to see that where, in the case of steel, the structure consists mainly of iron crystals, the escaping gas bubbles are often imprisoned between interlocking arms of such iron crystals, and thus lead to a more or less spongy mass. There is interest also in the fact that the iron crystals are largest where the chilling effect is least felt, namely, in the centre of the ingot, where, if " feeding " is not efficient, serious porosity occurs.

The consideration of the question of rapid chilling, and its effect on the ejection of gas bubbles with the formation of zones of weakness in an ingot, cannot be isolated from the important question of " segregation."

Colonel Maitland, in his paper on the " Treatment of Gun Steel," refers to the segregation of carbon in a gun steel ingot. The diagram therein presented, giving the percentage of carbon at different points in the ingot, when examined in the light of the foregoing remarks on the position of the gas paths, is strikingly interesting. It is here reproduced (Fig. 27) with the carbon percentages marked along the suggested " lines of weakness " or " main gas paths." It is unquestionable that along these paths the migratory particles travel, and are repeatedly found imprisoned —notably phosphide of iron (Fe_3 P), slag carried over from the ladle (green silicate of manganese) and sulphide of manganese.

In this connection it is instructive to again examine the diagrams (Fig. 2), which show the cooling by successive layers of an ingot. The lines *a.o.* and *b.o.* should be compared with those similarly marked on Fig. 15. It is evident that as each layer solidifies, the liberated gas is driven into the liquid immediately adjacent (Fig. 28).

SLOW COOLING.

In a slowly cooled ingot the gases can rise more readily and the zones of weakness are less pronounced. Unless, however, means are taken to specially keep the head at a high temperature the " pipe " will be deep. Herr Reimer's method of keeping the head molten, so as to fill the " pipe " as it forms, is open to the serious objection that segregation of carbon is likely to be very pronounced, and the central portion of the ingot of a coarse crystalline structure—a condition of things most undesirable, as forgings made from such ingots require considerably more work to create homogeneity of quality throughout their mass than do similar sized ingots more rapidly cooled.

In the afore-mentioned considerations no account has been taken of the influence of the elements carbon, manganese, and silicon on the formation of the " pipe," though, as pointed out by Herr Wahlborg in his paper on this subject, these elements have a most important influence on the position and character of the " pipe " in steel ingots. Ingot iron, practically carbon free, as is well known, will not lie quietly in the moulds when cast without the addition of either silicon, manganese, or aluminium, the reason being that the iron passes so quickly from the liquid to the plastic or pasty state that the gases contained in the iron, when liquid, cannot escape.

The addition of silicon, manganese, and aluminium apparently creates a liquid medium in which the iron crystallizes, and into which it throws its gases, such medium remaining liquid until the gases have escaped into the ingot head. The higher the carbon content, and the lower of course the temperature of solidification, the less marked is the influence of the plastic state on the retention of gas bubbles, as a reference to the curves of solidification will show. Ingots of high carbon steel, therefore, are liable to a deep central " pipe," especially if the manganese content is also high, and the temperature of teeming much above that of the solidification of the steel, for, as Mr. Brinnell has shown, the temperature of casting influences the " pipe " very considerably.

As this question of the influence of carbon and manganese on the " pipe " is an important one, it will be well to pursue it further.

If white iron be cast in a rapidly chilled mould, the gases will be found to have almost entirely escaped, and only a trace of "pipe" will be seen along the axis (Fig. 29). The contraction here will amount to about 1-60th of the original volume. The microscope reveals the fact that here the cementite plates in the eutectic (the cast-iron in this case having 4.2 per cent. carbon content) reach from the chill surface to the axis (Fig. 30).

In another similar ingot of lower carbon content, 2.5 per cent., the cementite (carbide) plates occur near to the ingot skin (Fig. 32)—contraction here 1-100th. The presence of the manganese increases the chill effect, whilst silicon decreases the same (dimension C, Fig. 32).

In an ingot of 1 per cent. carbon the chill zone (*c*) is still further diminished, and generally, the larger the ingot the smaller is *c*. for a given carbon content.

Rapid chilling, as already seen, brings about rapid gas escape, and is associated with the solidification of cementite; the larger the cementite content the deeper the chill, and the greater the tendency to deep-seated central "pipe." The presence of manganese would appear to assist the rapid solidification of the cementite (Mn_3C being formed simultaneously with Fe_3C, or possibly before it), hence aids central "pipe" formation. Silicon, by hindering the formation of the carbides, decreases the chilling effect of the ingot mould, and by thus causing slower solidification of the ingot, enables the gases to escape more effectively, and thus the upper portion of such an ingot acts as a feeding head. Aluminium acts in a similar manner to silicon, but owing to its extremely low specific gravity, probably affects the upper portion of the ingot more powerfully than the lower.

It follows, from the foregoing, that if, during the solidification of an ingot, its mass can be compressed in such a manner that the gases can be driven inwards, and caused to ascend and escape at the mould top, then ideal elimination of "pipe" has been brought about.

In the ingot compression methods now practised, viz., those of Whitworth and Harmet, rapid cooling is brought about, first by reason of the necessarily thick moulds (occasionally water-cooled externally), and secondly by reason of the constant contact maintained between the ingot and its mould—hence the amount of segregation in such ingots is not so great as in slowly cooled ones, seeing that the migratory elements, less mobile than the escaping gases, are imprisoned in the rapidly freezing steel.

In the Whitworth method, where pressure is introduced by means of a ram forced down on the upper surface of the ingot whilst this is molten, the top of the ingot is rapidly frozen, and an enclosed cavity occurs in a position fairly constant. The fact that the ram bears on the outer solid walls of the ingot, and is thus early brought to rest, militates against the ideal afore-mentioned, whereas, in the Harmet process, the lower ram pushes the lower portion of the ingot through a constantly diminishing mould, whilst simultaneously with this action the thickness of the bottom of the vase containing the liquid metal is being rapidly increased—conditions which exactly satisfy the requirements of the theory above expressed, namely, that for perfect elimination of "pipe" the mass of an ingot must be so compressed that the gases driven inwards by cooling of the outer envelope are forced upwards, and escape by the mouth of the mould. Further, in practice the compressing ram of the Harmet system is found to advance by a series of small steps, at each of which a vibratory shock is given to the ingot and mould, such agitation, as is well known, conducing to still more rapid crystallization and accompanying gas escape.

The foregoing notes were written in 1902, since which time the writer has had the opportunity of confirming many of the points raised and, in studying the many remarkable metallurgical papers which have since 1902 been given to the world by such experts as MM. Osmond, Charpy, Stead, Harbord, Talbot, Howe, Wedding, Baron Jüptner, and our own Professor Turner, he is more convinced than ever that gases play a most important part in the structure of both cast iron and steel, as well as in all other cast metals.

Nickel steel and all metals which, melting at high temperature, pass rapidly to the plastic state in cooling, are very liable to gas inclusion. Dr. Carpenter some time ago showed this when dealing with the subject of nickel wire tests, revealing the fact that during the rolling or drawing of the wire, occluded gas bubbles travel along the boundaries of adjacent nickel iron crystals until they reach the centre of the section (the hottest zone) of the wire.

As long ago as 1899 Messrs. Ewing and Rosenhain pointed out the presence of gas bubbles which had become entrapped between adjacent crystals during the solidification of cast metals, and when speaking of the numerous gas bubbles found in cast cadmium, arrived at the conclusion that during the crystallization, the crystalline elements build themselves around these gas bubbles in regular orientation. We have thus, as the result of the researches of Messrs. Ewing, Rosenhain, and Carpenter, the position of gas bubbles in cast and worked metals defined. They occur between the boundaries of adjacent crystals. Even in comparatively pure metals the crystals or crystallites are forced apart by attenuated gas bubbles and prevented from becoming welded together. M. Osmond and others have shown this to be the case with gold (analytically pure) a section of an ingot of which under the microscope distinctly showed fine boundary lines between the individual crystals.

The question of the influence of occluded gases during the actual growth of octahedral crystals of iron and nickel (and other metals) in separating the adjacent films of iron or nickel as they become deposited on the cubic or octahedral nucleii (which are first thrown out of the liquid solution during cooling) is another point not to be neglected, and it may yet be proved that the " slip-band " phenomena of Ewing and Rosenhain, as well as the curious " silhouette " figures of Messrs. Osmond and Cartaud, are closely connected with the presence of gases entrapped in the ferrite crystals at their very birth.

Again, Professor Turner suggested, in discussing Mr. Harbord's paper on " Tests of Basic and Acid Steel," that the possible explanation of the difference in hardness and tensile strength in basic and acid steels was connected with gaseous influence, and this would, on close investigation, appear to be the true explanation.

Basic steel, as is well known, is softer than acid steel of similar carbon content. Now, comparing the manufacture of the two steels, it will be noted that the acid metal in the Siemen's furnace lies in its bath under a blanket of highly silicious slag (a condition highly favourable to the elimination of gas) for some time before it is tapped into the ladle, and, by careful dead melting before and after the addition of the " finishing " (carbon, silicon, and manganese), the resulting steel is remarkably quiet in its running, and, according to the silicon content, is comparatively blow-hole free in the ingot state. Further, silicon enters into the composition of such acid steel, and as this element (Si) is not migratory one may conclude that the separation of the ferrite crystals takes place in a liquid medium consisting probably of a mixture of high carbon iron and silicide of iron, which, being very mobile, offers very little resistance to gas escape, and does not encourage the formation of iron oxide; or, if such is present, allows of its departure in company with the gas bubbles which escape towards the hottest portions of the cooling ingot. Silicide of iron has a hardening effect on the structure of steel, and this fact, combined with the freedom from gas porosity, explains why acid steel is harder than basic steel, which contains no hardening element in addition to the manganese (supposed to be of equal content in both cases under consideration), and which has its "finishing" added generally to the ladle, with the extra use of aluminium as a further help to gas escape. In the case of basic steel it is not difficult to see that under a thick lime (basic) slag in the furnace there is but little aid to gas escape, and that carbon and manganese additions *outside* the furnace as the steel runs from the furnace to the ladle, or from the ladle to the ingot moulds, do not greatly conduce to gas-free steel, especially when such carbon and manganese are added in a more or less cold state to the liquid metal. The further addition of aluminium in the ingot mould certainly assists gas-escape, but it is repeatedly found that the influence of aluminium in this respect is governed by the temperature of the liquid steel, the first and last ingots in a heavy cast being often distinctly different in their porous character.

That gases play an important part in the structure of cast-iron is certain, as every observant foundry man knows. Unless sufficient large feeding heads and risers are placed near the heaviest sections of a casting, blow-holes, cavities, or "pipes" are inevitable. It possibly has not struck everyone that the office of keeping a "feeding-head" alive is to allow the gases to escape from the molten interior of a casting and to give liquid iron the opportunity to replace the space recently occupied by the gases. When a portion of a casting is chilled the gases liberated there, when the iron (ferrite) crystals are formed, are driven at great speed through the eutectic surrounding such crystals, and should silicon be low and manganese be high, or, in other words, a "strong" iron be used, and the casting be run at high temperature, then the crystals of cementite (iron carbide, Fe_3 C) will arrange themselves at right angles to the chilled surface, such crystal arrangement following the gas paths, as before explained. An intelligent consideration of the gas paths when dealing with the casting of any moulded piece, however complicated, will show where heads, risers, and running gits should be placed for best results.

As in the study of the influence of silicon on the structure of acid steel, so, in the case of cast iron, silicon and manganese play an important part in connection with the escape of gases during solidification.

A cast-iron containing 3.5 per cent. of carbon and 96.5 per cent. of iron when fractured is white, whether cast in chill or in sand; if the same be re-melted, and 2.5 to 3 per cent. of silicon added, the resulting fracture is grey. Re-melt this grey iron, and add 4.5 per cent. to 5 per cent. manganese, and the resulting iron is white.

Microscopic examinations of the first alloy (3.5 per cent. C 96.5 per cent. Fe) shows ferrite crystals in the eutectic and innumerable small gas cavities appear in the eutectic portion. In such an alloy the period of solidification is very small, and should the casting temperature be much higher than the true melting point, porosity, due to gas inclusion, is marked, especially if the metal be cast in a chill. The presence of silicon in the second alloy, 3 to 3.5 C, 3.0 Si, 93.5 Fe) reveals in the eutectic portion, especially in a slowly cooled sample, crystals of silicate of iron, gas cavities being absent, but in the centre of the casting, at the point which was the last to solidfy, graphite in coarse flakes is seen, and, as might be expected, the higher the temperature of casting, and the slower the cooling, the higher is the graphitic content and the lower that of total carbon, owing to the escape of graphitic carbon as "Kish."

The effect of gas escape on the segregation of the liberated carbon as graphite is best seen when the above alloy is cast in a chill, or better still if a bulky casting is placed in water at the moment of solidification. (See Sample). Along the surface is a zone containing fine graphitic carbon, whilst in the centre is the zone of coarse graphite, driven thither along with the gas at the time the iron and cementite crystals were rapidly growing at the surface and expelling from between themselves the occluded gases. The outer zone is poorest in carbon, the inner the richest.

This fact is interesting in its bearing on another well known occurrence, viz., the outer skins of "chill-cast" steel ingots are lower in carbon, phosphorus, and sulphur (the migratory elements) than are the zones immediately (say ½in.) further towards the ingot centre.

The third alloy mentioned (C=3.5 per cent., Si=3.0 per cent., Mn=4.5 to 5.0 per cent.) when microscopically examined shews plainly the powerful influence of manganese. In the chill cast sample only a trace of graphitic carbon is found, the ferrite crystallites etch white, indicating the absence of that graphitic carbon which in the second alloy (C 3.0 to 3.5 per cent., Si 3.0 per cent.) was evident in the dark colouration of the ferrite crystals—obviously carbonized; the density of the structure is very noticeable, and its freedom from gas cavities, even under high power of magnification, is unmistakable.

In this case it would appear that the ferrite crystals first separate out from a solution which is practically "eutectic" (4.3 per cent. C) with manganese carbide and iron silicide dissolved therein. The manganese unites with the carbon, which would otherwise be liberated by the silicon as graphite. The cooling curve shows that this alloy solidifies more quickly than the second

(C, Si, Fe alloy), and confirms the statement that silicon promotes slow cooling, whereas manganese has the opposite effect. In other words, silicon, by keeping liquid the eutectic in which the iron crystals are growing, enables the gases to escape freely from between the fir tree branches of the ferrite, but by reason of the formation of the silicide of iron envelope around these iron crystals hinders the cementite (Fe_3 C) formation and sets free graphite which, in turn, carbonizes the ferrite crystals, such carbonizing being rapid at the high temperature obtaining at the time. When manganese is also present the iron crystals are not so carbonized seeing that free carbon is not liberated, it having been grabbed by the manganese to form (Mn_3 C) which raises the solidification temperature of the eutectic and hastens the period of the setting of the whole mass, as proved by the fusion and cooling curves.

Experience in manganese-steel manufacture confirms this statement that manganese hastens the solidification of cast iron and steel containing high manganese content. Thus, manganese steel cast at a high temperature into chill moulds is found to solidify almost instantaneously when the solidifying point is reached; the gases escape rapidly and leave marked zones of weakness along which the ingot can readily be broken (see sample). Further, the top of the ingot, if square, sinks during the solidification, leaving a convexity or · cavity exactly pyramidal in shape. Along the four corners of this recess the last gas bubbles can be seen coming off, and, when cold, the thin slag covering retains distinctly the bubbles which were finally entrapped in the congealing slag.

The higher the temperature at which iron or steel is cast the more gases are absorbed, hence the need for extra feeding and efficient venting of the moulds. Without any intention to recommend low temperature casting, the writer remembers in this connection the casting, at the end of a heat, of a mild steel magnet block, analysis C=.13 per cent., Si=.15 per cent., Mn=.10 per cent. The steel was so cold that it would scarcely run from the ladle, and the casting, or block, about 5 feet by 3 feet by 1 foot thick, was "short-run," the metal only rising into the head, or riser, about one inch. The casting was found to be perfectly sound, for when the inch of head was planed off no porosity was visible, and the weight of the block proved its solidity. In this case, evidently, the gases had escaped from the steel whilst slowly cooling in the ladle, for there was no "pipe" in the casting, the upper surface being perfectly level.

It will, in the writer's opinion, be clear from the foregoing that the gases set free during the solidification of the iron (ferrite) in the iron-carbon alloys, cast-iron and steel, play a much more important part in the structure of such alloys than is generally allowed, and it will not be surprising if, in the hands of skilled metallurgists, possessed of the necessary apparatus, it is proved that the "contraction," or shrinkage, of metal is almost entirely due to the driving off of gases set free during solidification.

Specific gravity and "dilatation," or expansion under heat, are obviously associated with this question, and it is interesting to note the following facts :—

1.	Specific	gravity of	pure iron	7.85 to 7.88	=	490 to 493	lbs. per	cubic foot.
2.	,,	,,	bar ,,	7.79 to 7.85	,,	487 to 490	,,	,,
3.	,,	,,	mild steel	7.60 to 7.80	,,	479 to 488	,,	,,
4.	,,	,,	pearlite ,, (.9C)	7.82	,,	489	,,	,,
5.	,,	,,	white iron 3.87C (1% Mn .15% Silicon)	7.68	=	480	,,	,,
6.	,,	,,	light grey iron (C 3.6 2% Si .6% Mn)	7.15	,,	447	,,	,,
7.	,,	,,	coarse grey iron (3.3% Si .5% Mn)	7.06	,,	440	,,	,,
8.	,,	,,	silicious iron 6 % Si	6.99	,,	432	,,	,,
9.	,,	,,	Spiegeleisen (12% Mn. C=5.3%)	7.50	,,	469	,,	,,
10.	,,	,,	ordinary foundry iron (powdered) 2% Si	7.15	,,	447	,,	,,
11.	,,	,,	the same (cast block)	7.05	,,	439	,,	,,
12.	,,	,,	iron carbide (Fe_3 C) (Moissan)	7.07	,,	442	,,	,,

The difference should be noted between the weight of white and grey irons (5 and 6) of approximately the same carbon content; this is not entirely accounted for by the different specific volumes of combined carbon and graphite. The true reason is probably explained by the presence of gas pores. This is confirmed again by the experiments of Thorner, Nos. 9 and 10 (Stahl und Eisen, 1886, and Jüptner: Siderologie II. p. 133). In this connection the specific gravity of the *non-expansible* nickel iron alloy (36 per cent. Ni) is of interest. Is this non-expansibility and high specific gravity (8.05) due to freedom from gas inclusion?

Professor Turner, in his paper on "Volume and Temperature changes during the cooling of cast-iron," showed clearly the effect of the various elements on the shrinkage of cast-iron, and in particular the influence of combined carbon, silicon, and phosphorus.

The higher the combined carbon content the greater is the shrinkage. If, as appears likely, high carbon content is coincident with freedom from gas inclusion, then it would seem that shrinkage and gas escape during solidification are intimately connected.

M. Osmond, in the discussion of the above paper, alluded to the possibility of the dissolved gases having an influence on the shrinkage and dilatation of iron, and gave the striking illustration of the case of water which had been boiled for a long period in vacuo (the gases thereby completely extracted) being frozen in a glass vessel *without cracking the same.* As is well-known, water increases in bulk on freezing, but here, on the absence of dissolved gases, the expansion did not take place. Is it not, therefore, very probable that the gases held by solidified metals are mainly responsible for the dilatations or expansions which accompany the allotropic changes, or those changes in carbon and iron equilibrium, which occur during the heating or cooling of iron and steel between certain temperatures? In the case of puddled iron, carefully worked under the "helve," and rolled with a special view to expelling all included slag and gases, a much denser iron results than is possible under modern conditions, where the ball is drastically treated under the steam hammer and rolled at the speeds and draughts of up-to-date mills, as was shown some years ago by Mr. Thomas Ashton. If such iron be annealed a softening takes place, the tensile strength being lowered and the elongation increased, whereas a dead-mild steel of similar analysis (with the exception of manganese, which is higher in the case of steel) annealed under the same conditions of temperature and time, is affected much more markedly.

It is not at all unlikely that the cooling curves of the iron and mild steel will show a difference, indicating greater expansions at the change points Ar_3, Ar_2 and Ar_1 in the case of ingot iron (mild steel) than in that of the wrought iron.

In well-worked puddled iron the gases are mainly eliminated before the ball is shingled, and the mass of iron grains, or full-grown ferrite crystals, are more or less mechanically freed from any gases which may remain, seeing that they can escape along with the liquid cinder. This cinder, according to the efficiency of the shingling operation (undoubtedly highest with the old helve action) and the subsequent rolling (non-reversing) is eliminated.

The porosity of wrought iron is chiefly due to slag, and can be readily traced under the microscope, the gas pockets being found in the neighbourhood of the pile marks, and not between individual iron (ferrite) crystals; it is very difficult indeed to always distinguish between gas bubbles and slag-pockets or shots. There is much more perfect welding of adjacent iron crystals in a good wrought iron than in ingot iron or mild steel, except when slag intervenes, obviously because the ingot-iron crystals are surrounded by gas films, or by the pearlite which occludes the gases last set free during solidification of the ingot.

The gas porosity of mild steel may largely account for its inferior resistence to corrosion.

In this connection Mr. Stead's remarks on the curious columnar structure in a mild steel bar (carbon .21 per cent) which had been annealed in lime for a long period are interesting, as showing how the gas escape paths in the ingot may persist even after rolling. Such a phenomena has not been observed in wrought iron similarly treated, the reason being obvious.

Many other questions have suggested themselves to the writer during the research before-mentioned, and the influence of gas on the formation of eutectics, viz., those portions of an alloy last to solidify, and hence last to allow gas-escape, is very striking. The minute gas bubbles which are the last to escape appear to leave tiny cavities behind them, into which, during the nip of final contraction, the soft ferrite apparently is forced just as the whole mass solidifies. In the micrograph (Fig. 32) this honeycomb structure is seen, and here and there the flattening of the bubbles, causing them to run into one another and coalesce in perfect parallel order, seems to the writer to indicate the method by which lamellar eutectic structures are developed.

This raises, however, a train of study quite apart from the scope of the present paper, though more or less connected with it.

The writer hopes that that which has been said may be suggestively useful to those who are interested in the solution of the many difficult problems which are ever arising in the work-day practice of the iron and steel worker, and in again referring to the subject of the paper, would draw the attention of the members to a sentence of M. Floris Osmond, one of the greatest of living metallurgists, in his great historic paper on "Metallography considered as a testing method."

In referring to the boundaries between individual grains or crystals in a metallic crystalline structure, he said :—

"Those surfaces of weakness constitute a natural receptacle "for the gases which may be evolved at the time of solidification, "or later, a way all prepared for the fissures which may be "produced or be propagated by mechanical means. Metallurgists "must therefore endeavour, if not to suppress them, which is not "possible, at least to attenuate them, by diminishing the quantity "of the gases, in preventing their evolution, in interfering with "the free action of the crystalline forces by accelerating the "cooling; in a word, by all the means suitable to diminish the "extent of the joints' surfaces, and to make them more "disconnected."

With reference to Figs. 16 and 17, showing the gas paths followed during the cooling of cylindrical and square ingots; in connection with the use of spherical moulds the writer remembers having on one occasion to produce a number of cast-steel balls, and made a chill-mould to rest on trunnions so as to revolve it during cooling; in that way he obtained a cavity at the very centre of the ball. Micro-photographs 22 to 26 prove that the crystalline structure of a cast ingot is determined by the direction of the gas paths. These micro-photographs were taken at certain points of the ingot, and they are shown in their relative positions; it will be seen that the direction of the crystals follows the gas-escape line. The wall diagram exhibited is really a copy of an examination made all over the surface of a chilled ingot, and the gases are shown as they escaped from the blowhole at the head of the ingot. Fig. 29 shows that if white iron is cast in a rapidly chilled mould the gases will be found to have almost entirely escaped, and only a trace of "pipe" will be seen along the axis. I have a sample here with the crystals reaching from the outside of the ingot to the very centre. There are three or four cooling curves on the wall, which show that the addition of manganese raises the temperature of solidification, but the further addition of silicon, in certain proportions, at once lowers the temperature of solidification. One of the sketches shows a blowhole in the bottom of an ingot, the gas-escape paths, in this case *downwards*, being shown in a small ingot exhibited on the table.

SUMMARY.

Summing up the substance of the paper, the writer has attempted to show that:—

(1). Steel and cast iron contain, when molten, gases in solution; and the higher the temperature of the liquid alloy the greater was the quantity of the gas dissolved (such gases being mainly C O, H, and N).

(2). At the moment of solidification such dissolved gases are thrown out of solution, and as the cooling metal solidifies layer after layer ejects its gas into the still molten interior of the mass.

(3). The direction of the escaping gas bubbles is towards the hottest zone of the liquid mass. Thus, if the top of an ingot be kept liquid the occluded gases escape thither, whereas if the bottom or side of an ingot be kept hottest, and an exit for the gases be provided, they, the gases will escape by such paths. The "pipe" in ingots and castings is directly traceable to escaping gases.

(4). The escape paths of the gases in polygonal ingots or castings follow the bi-secting planes between adjacent sides, such planes constituting planes of weakness, tests across which often reveal actual separation of adjacent planes.

(5). The migratory elements, graphite, sulphur, phosphorus, and slag occur along these zones or planes of weakness, and are the explanation of ghosts or phantoms in steel forgings.

(6). Rapid chilling when elements promoting formation of carbides are present, such as Mn and Cr, tends towards the elimination of gases, because there is no intermediate plastic stage between the liquid and solid states.

(7). Slow cooling when elements which assist the rapid growth of the ferrite crystals are present, such as silica and aluminium, aids gas escape.

(8). Silicon and manganese together aid the escape of gases by keeping liquid the matrix in which the ferrite crystallites grow, hence, with the aid of mechanical compression, steel containing sufficient quantities of Si and Mn may be made practically free from serious gas holes.

(9). The crystalline structure of small chilled ingots of cast iron, microscopically examined, shows that the so-called columnar structure observed at the surface of chill castings is due to gas escape. The plates of iron and manganese carbide and the axes of the ferrite crystallite are arranged in order along the gas escape lines. In the absence of silicon and aluminium, and especially when steel or cast iron is cast at low temperatures gas bubbles are found entangled between the ferrite and carbide crystals.

(10). The gases held in initial solution are not all eliminated by the above methods.

The difference of volume of a casting before and after solidifying is due mainly to the difference in the volume of the dissolved gases in the two states. Contraction is, therefore, probably the shrinkage due to gas escape.

(11). Dilatation or expansion of bars when re-heated is also probably due to the expansion of gases still retained in solid metals. Steel and iron bars respectively re-heated contract in volume, whereas grey iron, because of expansion of graphite, expands (up to a certain point), white iron, however, which contains but little imprisoned gas, does not contract after repeated re-heatings.

(12). The failure of steel and iron, as shown by Mr. Rosenhain, occurs along the " slip planes." In the initially formed iron cystals each film of iron is separated from its neighbour by a film of imprisoned gas or other impurities, and it is along these film planes probably that the crystalline slip occurs.

Gas porosity, therefore, is largely associated with the phenomena of dilatation, and is possibly a dominating factor in the phenomena of recalescence in iron and steel, and also plays an important part in the changes effected by the annealing of steel and malleable iron castings, and in the quench hardening of steel.

THE DISCUSSION.

The **President**: We shall be glad to have your views and criticisms upon this paper, and I have no doubt there are many of you who are very anxious to tell us how far you agree with Mr. Fletcher, and how far you differ.

Mr. **Frank Somers**: I do not want to criticise the Harmet system of compressing ingots, whilst in the fluid state, to make them sounder, but from a commercial point of view I should like to compare it with the fluid top processes of both Herr Riemer and Herr Beikirch. The method of keeping the head or top of the ingot molten in the Riemer process is by using gas and air, and in the Beikirch process by forcing cold air through an incandescent body of coke. The result obtained from both these processes is very much the same.

I should like to know what is the extra cost per ton of producing a 20 ton ingot under the Harmet compressing system, and also what the initial outlay would be in putting down the press, etc. I think it would be considerable. The cost of putting down the plant for making ingots with fluid tops would only be between £300 and £400.

As far as our experience goes, if a customer orders a forging, he does not trouble so much about the test of the ingot, as of the result of the test from the forging itself, after being annealed. Under the Harmet system the test from the ingot itself is, I believe, superior to any test from any other ingot made by a different process, but when it comes to the forging which has been produced from one of the three processes I have mentioned, and afterwards annealed, I do not think that one could, from the test results, tell by which process the ingot had been made from which the forging was taken, and so I do not think that the enormous outlay and heavy cost per ton in producing ingots under the Harmet system justifies the result obtained. I think it is advisable that all forgings should be produced from sufficiently large ingots in the first place, under a large press, for we find that by doing this we get fewer "wasters." Even with Harmet ingots, if small ones are used and only a little work put on the forging, surface defects, due to small cracks, will appear on machining the forging.

With regard to the comparative merits of basic and acid steel discussed on page 49, as far as we are concerned we use both open hearth basic and open hearth acid steel, and from actual results of tests made by us have found the open hearth basic superior to the open hearth acid. In most cases the analysis of the basic steel will give lower percentages of both sulphur and phosphorus than the acid steels.

Of course, the objection to open hearth basic steel is that inferior ores can be used in its manufacture, but when this is the case, the result is a poorer steel.

There is nothing to prevent steel manufacturers using inferior ores for either process if they wish to, but it would be easily detected in working the steel.

On page 50 Mr. Fletcher touches upon the very important subject of the feeding heads on castings. In this country I believe there has lately been trouble with regard to unsound steel castings. I have two photos here, showing two steel castings before dressing, one being the ram for a warship, and the other part of a ship's frame. They are German castings, and the heads are equal in weight to that of the castings when dressed. The makers claim that owing to the size of the heads they get much sounder castings, and are able to sell them to us. I may mention also that the majority of German steel castings are made by the basic open hearth process.

About three months ago, when in Germany, I was shown several castings for British firms, and told that although in the first place it costs more money to put such large heads on, yet in the end it is cheaper, as fewer wasters are made.

Mr. W. J. Foster : There is one point that struck me on cast iron, page 50, as to silicon. He says : " As in the study of the " influence of silicon on the structure of acid steel, so, in the case " of cast iron, silicon and manganese play an important part in " connection with the escape of gases during solidification. A " cast iron containing 3.5 per cent. of carbon and 96.5 per cent. " of iron when fractured is white, whether cast in chill or in sand; " if the same be re-melted, and 2.5 to 3 per cent. of silicon be " added, the resulting fracture is grey. Re-melt this grey iron, " and add 4.5 per cent to 5 per cent. manganese, and the resulting " iron is white." Can the author give us an idea of what gases are present in cast iron? I find that Nos. 1, 2, and 3 iron, with high silicon, make a solid casting without blowholes. No. 4 pig iron, with practcially the same constituents, except that the silicon is a little lower (perhaps 1 per cent.) will make a casting with a lot of blowholes in it. If we go on to a No. 6 pig, of the same composition with the exception that the silicon is considerably lower, we again get a solid casting without any blowholes. My opinion is that blowholes in cast iron are not all due to gases, though it may be so with steel. As far as pig iron is concerned, I don't for one moment think that we have gases present.

Mr. Charles Higgs: With reference to the absorption or occlusion of gases in iron and steel and other metals, we know that silver will absorb 22 times its own volume of oxygen, which it again liberates at the moment of solidification, with the result that one gets a rough ingot covered with little volcanoes and craters caused by the oxygen escaping from the porous ingot. The same thing happens with copper, if it is not treated with care. I should like to ask Mr. Fletcher if he thinks that aluminium deteriorates the strength of iron and nickel.

Mr. Samuel Moore referred to the patent casting process of Messrs. Robinson and Roger, the plant being made by Messrs. Davy Bros., Sheffield, and wished to know whether it had been a success. He was very much interested in reading an account of the press and squeezing process described by Mr. A .J. Capron at the Iron and Steel Institute, and would like to hear how it was developing.

Mr. F. S. Wilkinson: Mr. Fletcher refers to the outer skins of castings. In a paper given by Mr. Talbot on the segregation of steel ingots, before the Iron and Steel Institute, an analysis was given which showed that at one part of the ingot the proportion of sulphur was .018 per cent., whereas at the top of the ingot, and near the outside, it was .035 per cent. Lower down the sulphur increased until at the bottom it was .05 per cent. And from a point about a quarter of the distance down the ingot, to the centre, it increased, and was as high as .267 at the centre. It appears to me that the sulphur would tend to segregate in the ingot towards the centre, but why should it be .018 near the skin about one quarter of the way down, and increasing to .05 towards the bottom?

The President: We have had a very interesting and suggestive paper from Mr. Fletcher, certain to give to many of us new ideas and lines of thought that we may follow out profitably. As regards the question of the steel, I don't feel competent to traverse what Mr. Fletcher has said, but with reference to cast iron, with which I am more acquainted, whilst there may be some truth in what he says, yet with respect to the functions of the gases I am afraid he claims too much. It appears almost as if gas plays that part in cast iron which many of us believed graphite, or carbon, was doing. Mr. Fletcher has not made it quite clear whether rapid cooling or slow cooling does most in eliminating the gases. I think there is very little doubt that it is not the gases that cause what we know as "sinking" in cast iron. When you get a pocket in a casting which has been caused by gas, the interior of that pocket is white and glazed, but when you get a "sunk" portion, the interior is black, or dark; and that difference in colour is what differentiates between a blowhole or a sunk hole. We have usually associated contraction in a casting, whether excessive or little, with the amount of graphite which is available. Take an iron which is high in total carbon; if you turn the whole of that carbon into graphite, your contraction is small. If you have little carbon and turn it into graphite the contraction is great. So that contraction is not only a question of the condition of the carbon, but it also depends upon the total amount present. If one were casting a block of iron weighing 1 cwt. and poured hematite into the mould, you would find considerable liquid contraction. It would sink in the course of solidification. If you took the same mould and poured grey iron into it, you would have less shrinkage; and if you take a similar block and put cinder pig, containing 2½ per cent. of phosphorus, into it, you won't have any sinking at all. These things I have done. Now I should like to know from Mr. Fletcher how, on his theory, he can give an explanation of those different results. As regards the cinder pig, I think I can suggest one reason why it does not sink, and that is, as Professor Turner shows, that with hematite you have two expansions, and with grey iron you have three. Without detaining you further, gentlemen, I think you will agree with me that the paper deals with a subject of enormous difficulty, and as I explained to Mr. Fletcher before we began, this theory of the action of gases is one of those things which is perhaps as difficult to prove as to disprove. It is a matter which involves much thought. Mr. Fletcher has evidently put a great deal of work into his paper, and we owe him our sincere thanks, which I move we convey to him.

Mr. **Piper** seconded, and a hearty vote of thanks was carried by acclamation.

Mr. **Fletcher**: Thank you very much for your patient listening to what I felt to be, perhaps, rather a dry paper to some of you. First of all, let me reply to Mr. Frank Somers' remarks. He mentioned two systems of ingot compression, or two systems of attempts to make ingots solid. One was the compression method of Harmet; and the other of Riemer. I cannot quite give him the figures he asks for, but I think, as far as the question of cost is concerned, that the Riemer process is cheaper than the Harmet. As regards the forging of two similar sized ingots, one by the fluid compression system and the other by the heated top system, I may first say that my experience is that a smaller compressed ingot can be used, if necessary, for giving the same *quality* of forging as a larger non-compressed one. As to the two methods of forging, the compressed ingot has, to begin with, a certain value that the slowly cooled ingot has not. If you test the Harmet ingot you will get 20 or 25 per cent. elongation, whereas from a Riemer ingot you may get only 4 per cent. As the result of that, you could use a 'smaller compressed ingot than you could a Riemer ingot. With reference to the remarks of Mr. Somers about open hearth basic steel, in my paper I only point to certain dangerous elements in the manufacture of basic steel. Basic open hearth steel compares quite favourably with acid, although our own Government refuses to believe that it is so, and will not accept basic steel for the manufacture of guns. As to large feeding heads being provided, there is no doubt about the wisdom of that course, for if you want a perfect steel casting you must feed it. With reference to the difficulty of casting locomotive wheel centres. It was very difficult at one time, and many means were tried for preventing the breakage of the rim between the heavy balance weight and the light section; eventually the trouble was overcome by putting a "head" on the balance weight and feeding it well. Mr. Foster rather threw doubt upon the very bad influence of gases, and practically the same point is raised by Mr. Buchanan. I still hold that gases are mainly responsible for the results which have been mentioned, not only directly, but indirectly. The presence of manganese in iron is very important, as those curves of solidification in my diagrams show. If you add silicon, or manganese, separately to iron, it raises the temperature of solidification, but if you add them in certain proportions they lower it. Where you have silicon and manganese in the proportion of 2 to 1 you nearly always get (apart from basic steel) a sound ingot, giving a satisfactory test. I think that temperature also, along with the influences of silicon and manganese toegther, is largely responsible for the freaks which so often disturb us. Those three should be considered altogether. If you have silicon in iron, and allow that iron to cool, a point is reached where the carbon is thrown out, and the iron crystals have meanwhile done growing. Carbon, silicon, and manganese cannot be considered quite separately or together, without taking into account the temperature also, and those three items, if we knew sufficient about them, would explain, I think, the difficulties which as yet have remained unsolved. Now Mr. Higgs mentioned the matter of copper ingots. I know the gas difficulty is very great in bronze castings. Certainly, Mr. Eaton Shore gets remarkable tests. I believe also the brasses of Willans and Robinson's engines wear marvellously. I think if aluminium is used cautiously in cast iron, steel, or nickel, that it has very little deteriorating influence on the strength. Mr. Moore asked about the Rogers' system. The first part of my paper was written before Mr. Rogers' process was brought forward. I believe the system is perfectly successful. He compresses the ingot from the side, the top being still open to allow the gases to escape there. Mr. Wilkinson mentioned a paper bearing on the subject of segregation in ingots by Mr. Talbot. If he will turn to the discussion on that paper he will find the views of Professor Bauerman, who gives certain diagrams, showing the influence of sulphur. Fig. 2 in my paper gives sulphur and phosphorus segregation curves in an ingot. Those curves almost coincide with the freezing curves that I have suggested in several other figures. With reference to the President's remarks on " sunk " and blowholes, I agree with him that carbon condition is largely responsible for shrinkage differences in cast iron, but am convinced that *these differences are coincident with differences in the rate of gas escape.*

I have shown that silicon present in molten cast iron (at least up to 3 per cent. silicon) retards the cooling action and keeps the metal liquid, during which time the gases can escape. The carbon, in presence of silicon of sufficiently high percentage, takes the graphitic form for the reason that the silicide of iron envelope which surrounds each ferrite crystal prevents the carburization of same (formation of iron carbide). The graphite present is, because of its lightness, eminently migratory, and travels with the escaping gases towards the heavy portions, which, if not properly fed, sink or leave unfed cavities of the dark graphitic appearance alluded to by Mr. Buchanan. In cast iron having low silicon percentages, No. 6 for example, mentioned by Mr. Foster, the carburization of the iron crystal proceeds rapidly, and the whole mass of the metal freezes before the gases can entirely escape—hence the blowholes.

High-phosphorus iron does not shrink because of the presence of the phosphide eutectic, which allows the gases to freely escape. I have noticed that in such iron the surface of the cooling casting is perfectly quiescent almost up to the moment of solidification.

From numerous experiments made in connection with " cementation " of iron and steel by means of the gases C O, with and without N, and by contact with molten cast iron, I am of the opinion that the combined carbon state in cast iron and steel is the result of cementation of the ferrite crystal by the gas C O. Such cementation or carburization is facilitated by the presence of the gas N and of the elements Mn and C, but is retarded by the *presence* of Si, Al, and Ni.

It may be concluded, therefore, that cast iron high in silicon and low in combined carbon may suffer by slow cooling through the excessive segregation of graphite, and may be improved in mechanical properties by hastening the cooling wherever practicable. On the other hand, harder irons, rich in combined carbon and low in silicon, should be *cooled slowly,* so that the gases may escape, and in order that the outer surfaces of the casting may be free from the chilling action which brings about a hard, brittle, cementite outer zone, which is liable to fracture during that expansion which accompanies the recalescence of the interior greyer mass.

In conclusion, I should like to point out that there are a number of samples on the table, for the inspection of the members, which will, perhaps, illustrate some of the items in my paper more graphically than anything I can say.

The samples were examined with considerable interest.

The fourth meeting of the Session was held at the Institute, Dudley, on Saturday, the 21st December, 1907.

The President (Mr. Robert Buchanan) presided.

The minutes of the previous meeting were read, approved, and signed.

Mr. W. E. Dudley was elected a member of the Institute.

Mr. Alexander Jude then read the following paper, which was illustrated by a number of samples and drawings.

EPITOME OF PAPER ON THE VARIABILITY OF STEEL.

By ALEXANDER JUDE,
(of Birmingham).

The *point of view* is that of the steel user.

The *object* is to point out the great range of variation in all the test results from similar articles made to one specification, to correlate the variable functions, and to elicit reasons for the variability.

The *articles* experimented with in the present investigation are forged crank shafts of similar design, ranging from 4in. to 8in. sizes, the diameter being a rough gauge of the size of the forging. All forgings were by two makers only, and thus the general treatment throughout would be expected to be fairly uniform.

The *number* of forgings tested was 100, a large enough number to give fairly reliable percentages.

The *specification* was of the usual type, and called for an ultimate strength of 35 to 38 tons, with not less than 25 per cent. elongation on 2 inches, with the usual clauses relating to treatment of ingots and annealing similar to those for the Admiralty.

The *tests* made were :—

(1) Tensile test—noting ult. stress, elongation, reduction of area and appearances;
(2) Impact test—by pendulum machine;
(3) Analysis;
(4) Microphoto—to uniform magnification;
(5) Note of size of forging.

All test pieces were taken from similar positions in the crank webs, and those recorded in the present series are all longitudinal specimens.

Attention is drawn to the importance of the appearance of the side of the fractured tension bar. This appearance is only casually observed nowadays and hardly ever recorded—indeed, I am not aware of the existence of any method of comparison other than the one I now propose. I have herein called this appearance the "*Tenside*," and have sorted it into 9 grades (numbered 0, 1, 2, 3, 4, 5, 6, 7, 8) from very fine to very coarse.

Fig. 6. is a photograph of a series, full size. I, however, refer to a box of specimens when making comparisons.

Collecting up the various test results the following matter is obtained :—

(*a*) Ult. tensile strengths sorted out in one-ton ranges give Fig. 1. This shows an enormous percentage outside the specified limits. It may be here remarked that there is nothing very exceptional in this percentage. Other series and grades of steel give very much the same result.

Query 1. Is this variation due to variation of grade or variation of condition?

(*b*) Fig. 2 gives the average values of the elongation and reduction of area on the same basis as in Fig. 1. These curves appear consistent with the basis, but do not really answer *Query* 1.

(*c*) Fig. 3 gives the average analysis (C and Mn only). The other elements are practically uniform on the averages.

These curves show that in answer to *Query* 1 variation of condition is to be suspected as the cause of failure to meet the specification.

(*d*) Fig. 4 gives the relative impact strength for two-ton ranges, and shows a very large variation.

(*e*) Fig. 5 shows the average impact strength and the average tenside. (The average numbers, of course, come out fractional).

Note that the position of best values coincide remarkably at a 35-ton tensile strength. These curves strengthen the answer to *Query* 1, that variation of condition is the cause of the trouble.

(*f*) The micro-structure appears to vary greatly, especially in grossness. Thus for similar patterns of structure one

> forging may give an exceedingly fine structure, while another, even of the same size, a structure exceedingly coarse.

Fig. 7 gives typical instances. The corresponding mechanical tests are also given.

Micro-photos have been taken of all the specimens, and they are therefore too numerous to reproduce here, but will be shown at the meeting.

The first series is sorted according to the tensile strength in two-ton ranges, and then arranged in order of the impact strength.

The general trend as in the examples of Fig. 7 is observable in each group of the series.

Also if from the whole lot of the tests we take
All the very fine micros,
All the very coarse micros, and
All the remainder or medium micros,

We have :—

	Very Fine Micro.	Medium Micro.	Very Coarse Micro.
Average Impact Strength	4·45	2·51	1·95

The second series is sorted according to the tensile strength as before, and then arranged in order of the tenside.

This arrangement shows up a little better than the first series.

We also have the collective results :—

	Very Fine Micro.	Medium Micro.	Very Coarse Micro.
Average Tenside	1·95	3·05	4·23

The micro-structure also follows the elongation and reduction of area, although to a practically immeasurable extent.

This is shown in Fig 8.

The size of forging appears to have a comparatively small effect on the test results, but it is observed that it is easy to find a gross structure in a small forging, but not so easy to find a fine structure in a large forging.

Adopting the previous method of selection, we have :—

	Very Fine Micro.	Medium Micro.	Very Coarse Micro
Average size of Forging represented by the diameter.	4·91	5·53	6·03

Considering the above results collectively, *Query* 1 may be answered that it is variable condition that is mainly responsible for the erratic departure from the specification.

Figs. 1, 5, and 8, taken together, indicate that for the tensile test alone to be the criterion of what is good or bad, the allowable range is only a ton or so (not four, as is usual), and that all outside this narrow limit have the evidence of probability condemning them. In order, therefore, to prove that an outsider is an exception, and that its tensile result is in accordance with its real grade, or that it suffers from a curable fault of condition, some other test is necessary.

At present the attitude of steel makers appears to be very antagonistic to any test out of the usual run, but it is submitted that it would be a saving to both steel maker and user were it not so.

The further question submitted for discussion is, " What is the reason for all this variability of condition in spite of routine treatment, and is it commercially preventible?"

THE DISCUSSION.

Mr. J. ERNST FLETCHER : W have listened to a most abstruse paper, giving, I am sure, something to think about both to members who have had any experience of the manufacture and the heat treatment of forgings, as well as those not acquainted with this branch of trade. There are several points in Mr. Jude's contribution I should like to speak on. First, the test pieces seem to have nearly all been taken from rather difficult forgings. I have had some experience with this class of work, both large and small, and Mr. Jude could scarcely have selected a more severe series of tests, from a steelmaker's point of view, than those he has reported to us upon. Of all the positions associated with forgings the particular places to which he applied his experiments are those which have given the steelmaker the most trouble and anxiety. The web of any crank forging is always a peculiarly difficult situation. I should very much have liked to see for comparison the results of the tests taken from the ends of the same forgings. Members who have had to do with forging large masses of steel will bear me out when I remark how difficult it is to successfully forge a locomotive crank axle for instance. You are there dealing with a block of material, the web of the crank, necessitating in respect of that particular portion an entirely different mechanical treatment in the process of manufacture from the two ends of the forging, which are rounded off. If you follow the molecular movement (or attempt to follow it) in the web during forging, you will see how easy it is to arrive at the conclusion that in the centre of the web there is a great deal of confused motion going on which is absent, in the ends for example. Perhaps it is this difference in the condition of the mass under treatment that accounts, to some extent, for the curious results reported by Mr. Jude in the web of the finished shaft when examined either under the microscope or by tensile tests. I have taken notice of the peculiar state of the outsides of the test pieces in the many thousands of tests I have seen, and agree with Mr. Jude that the tenside is an indication of the steel-condition. The matter which has been raised by the author is a very difficult one to deal with by even those who are engaged at our very first-class steel making concerns. As a rule the carbon percentage in a locomotive crank axle is lower than will be found in the description of forgings which have been chiefly brought under our attention this evening. Yet, as I have said, it is almost an impossible thing, in actual steel works practice, to get the tests uniform even in locomotive crank manufacture. Mr. Jude's experiments dealt largely it seems with steels having a carbon percentage ranging between .4 and .5 per cent. In this respect also the author has taken steelmakers at their worst, I mean with a very trying condition of metal. There is no steel composition more notoriously troublesome for a maker to handle than material with just this range of carbon as an ingredient. Steel tyre manufacture may be quoted in support. All steel tyre producers are agreed as to the great trouble in producing uniform test results. Probably no more care is exercised than in the making of forgings for tyres. Yet uniform results cannot be got, although exact uniformity may attach to the size of the ingots employed, the method of ingot heating, the size of the blooms, the forging, rolling, and the heat treatment to which the forgings are afterwards subjected. Further, this lack of equal results will occur even at works where the greatest and most scrupulous care is exercised in superintending the processes. In locomotive crank shaft forgings also it is the web that causes the greatest perplexity. And, if the test is taken cross-wise and length-wise of the web totally different results are obtained. I notice that Mr. Jude has taken all his tests in one direction. This is not only unfair to the steelmaker, but it is contrary to engineers' practice. There are many locomotive engineers who, in testing crank axles, take their tests cross-wise and length-wise of the web. These gentlemen find by experience that sometimes a cross-cut will give, say, a bad test, while a length-wise cut from the web of the same forging will present a fair test, or it may be *vice versa.* But what I wish to impress is that there is no uniformity, and no golden rule for it. So for the author to expect the same is to expect the impossible. Another point I should like to remark upon is the difficulty in the annealing of forgings. A certain proportion of the defects we have been speaking of to-night can undoubtedly be attributed to this cause. As a rule, and I speak from experience, the outside of forgings gets better annealed than the inside. One important factor determining the thoroughness of the annealing process is the position of the forging in the furnace. To be successfully annealed forgings should be lifted up well above the floor of the furnace. I have known cases where failures in forging tests have been due to the material touching the floor of the annealing furnace, or being too near to the floor. Micro-photograph, tensile, and other tests taken from the spot where the casting has lain on the floor, and then from places which have been well free of the furnace bottom, have given opposite results. Mr. Jude states that he has presented his subject from the point of view of the steel user. He asks, " What is the reason for all this variability of steel condition in spite of routine treatment?" Speaking from a steelmaker's standpoint, while not able to give an answer to all his questions respecting the causes of the admitted absence of uniformity, I can assure the author that he will have very great difficulty in obtaining any advance upon present-day practice, even from the very best of our forging firms, so long as he asks for forgings containing between .4 and .5 per cent. of carbon. That is my experience, and I believe it is the experience also of most of the big firms who have to do with the making of high-class forgings in Sheffield to-day. I daresay it would be a very good thing, particularly for the user, if it were possible to get less diversity in the tests, but it is little use, I imagine, crying out for the unattainable. In my opinion many of the ingots employed in modern forgings are altogether too large for successful treatment. But this is a matter, I am aware, not altogether avoidable, owing to the demands of Government engineers and others, particularly the Admiralty. I noticed from Mr. Jude's remarks that in testing for composition manganese alone has been taken into account, and no notice has been taken of silicon. Now, silicon has a great influence in cast iron, and there is no doubt that it has quite as great a function in combination with manganese in steel, I may particularise that in tyre-making a very much higher percentage of silicon is allowed than in the generality of forgings. That this ingredient is important is shown by the circumstance that the shrinkage in French forgings has often been reduced to a considerable extent by increasing the percentage of silicon. I spoke just now of the size of ingots. One disadvantage which sometimes results when the ingot is over large is that in the event of slow cooling it will develop a very coarse fracture in its centre. That coarseness is never entirely got rid of in the subsequent forging, especially in the heart of the forging, and the quality consequently suffers. Sometimes a small ingot forged down will give a much better forging ultimately than will an originally large ingot. I believe that some of the best works now forge down blooms to begin with, and then from the bloom re-test the material, and then forge the crank. By so doing they are able to get a more reliable result than by forging direct from a large ingot. Mr. Jude enquires whether the variation in results of which he complains is commercially preventible, and he remarks that the attitude of steelmakers appears to be very antagonistic to any tests out of the usual run. Having had some experience of the difficulties of which he speaks, I am sorry to say that much is yet to be learnt in the science of forging and treatment of steel before Mr. Jude will get entirely out of his difficulties. As to the suggestion that additional tests should be applied, the steelmaker has rather a rough time in attempting to meet the tests already imposed. It is therefore easy to understand why they are antagonistic to any fresh ones. My reply to Mr. Jude's enquiry whether a greater uniformity in results is commercially practicable is that additional tests must mean additional cost in production. Prices of finished forgings would probably go up very considerably. If consumers are prepared to pay these increased prices, then, of course, it would be a matter for them to decide what they would like. But already quite ridiculous tests are often asked for, and, personally, I do not believe that better results would accrue from any further tests. These would probably be as likely to mislead as to advance the practice of to-day.

Mr. B. J. Dudley: I was rather struck with the range of the average strength of the forgings experimented upon, namely, 35 to 38 tons, and I see the actual range has been from 29 to 42 tons. Improved processes of manufacture which are steadily being adopted by steelmakers will undoubtedly improve the class of forgings turned out. Presses have very largely taken the place of hammering, and with very superior results. Before the application of the press it would very often happen that while tests taken from the outside of the forgings, say at the end, were satisfactory, as we proceeded inward they became less so, until at the very centre the test was very unsatisfactory indeed. It was evident that one of the causes of this irregularity was that the hammers were not heavy enough. The employment of the press does away with this trouble almost entirely. The metal is manipulated now right to the centre of the ingot, and we get rid of much of the variability of which Mr. Jude has been speaking. A great deal depends upon the power employed, and also upon the size of the ingot. I agree with what Mr. Fletecher has said concerning the extreme severity of the spot chosen by Mr. Jude for making most of his tests. Mr. Jude has told us that he mostly tested the web. He could not have chosen a harder part for the steel producer, and should make allowance accordingly. If Mr. Jude gets a good test from the web he can rely upon having got a good crank throughout.

Mr. James Piper: I should like to ask how many different ingots the 100 tests represented—I mean how many of the tests were from the same ingot?

Mr. Jude: Perhaps not any two from the same ingot.

Mr. Piper: If the author wanted a forging to bear a 45 tons tensile strain with a 35 per cent. elongation, what carbon percentage would he expect to have in it?

Mr. Jude: I don't know; I should leave it to the steelmaker. I should not ask for such a composition myself; someone else might.

Mr. Piper: If Mr. Jude wants another subject for experiment at any time, and will take an ingot and plane it down each side, and will test its centre also, I will guarantee he will get results much more surprising than any mentioned to-night.

The President: Those who have heard the paper to-night must, I am sure, agree with me that it is a digest that must have entailed an enormous amount of work upon the author. Even to pass 100 tests through one's hands, and to tabulate them, and try to get at the meaning of them, involves a great deal of laborious work, without attempting to set those experiments down in the form of a set communication to our Institute, as has been done to-night. There are many points of view from which Mr. Jude's subject may be regarded. But there is one point that I think must have impressed most of us. That is, that the heat treatment spoken of in the paper, and the resultant size of the grains of the metal, largely determines the character of the tests obtained, and the appearance of the micrographs. I gather that this is Mr. Jude's own experience also, since the members will have noticed that he spoke of returning forgings to the works for further heat treatment when he found the grain to be of a coarse grade. I was struck with this, recognising how this practice corresponded with that adopted by Mr. J. E. Stead in attaining improvements in steel rails. Evidently increased heat treatment is often what is needed for forgings, though the knowledge of the particular change they go through is not yet definitely fixed. Mr. Jude attempts to describe it by the word "condition" of the metal. But in my view the definition is insufficient; and seems an attempt to describe a state of things we know little or nothing about. The tests we already possess, such as the micro-photograph, tensile test, and analysis—these tell us something of what we want to know. But evidently there is much which is still mysterious and insufficiently explained or ascertained. Mr. Jude emphasises that the micro-structure in his tests varied greatly, especially in coarseness. Thus for similar patterns of structure one forging *might* give a very fine structure, while another, even of the same size, a structure exceedingly coarse. The members will have recognised that the coarse structure of which the author shows as existing in some large steel forgings is on all fours with what is found in many iron castings. Again, large forgings are evidently not so amenable to heat treatment as smaller ones. It would be possible to change their structure by rapid cooling, no doubt, but whether that would give the exact results required I am not prepared to say. Large bodies of metal, if allowed to cool naturally, will be certain to give a coarse structure.

I move a very hearty vote of thanks to the author for his able paper, of which I should like to say again, that its preparation must have involved a great deal of labour.

Mr. **James Piper** seconded the vote, and it was carried.

Mr. Alexander Jude: In the course of the discussion Mr. Fletcher has referred to the position from which I took the tension tests; in fact, all the tests. He objects to the test pieces being taken from the web, and suggests that the ends should rather have been tested. I have on several occasions done so to satisfy curiosity, and I can certainly confirm Mr. Fletcher's observations, for the ends do, as a rule, give better tests than the webs. But tests from the ends do not really meet the case at all, for it is the very web metal that we require to be most particular about. I have seen many broken crank shafts of various sorts, and in general they break in the vicinity of the web—often right across it—a point in favour of bent crank forgings. The stresses in and about the webs are not of the simplest character, and there is every reason why the critical test pieces should be taken from the webs rather than from places where the stresses are of a simple kind and the forging less open to suspicion. I would point out that we do not take the bars from the very inside of the mass. Surface stresses are generally greater than internal stresses, and it is the surface strength we are more concerned with.

It is, therefore, desirable to take the tests from the outer zones of the mass, although, of course, different articles are best judged on their own merits.

Mr. Fletcher further enquires for the transverse test results, those referred to in the paper being all longitudinal. Transverse tests were taken in all cases, and I found that they gave from one to two tons lower tensile figures than the longitudinal. The transverse test is certainly useful in indicating the existence of undue streakiness in the structure. The reason I did not give the transverse test results in the paper was because I did not desire to encumber it unduly, especially as they did not add much information to the points at issue. In regard to the silicon content, I do not think that *in this series* either silicon or the other residual elements would vary sufficiently to greatly modify the general deductions. Of course, the omission of a complete analysis of each sample is unfortunate, but the plea of great cost involved must suffice in the present case. As to the size of ingots employed in the manufacture of forgings, I am inclined to agree that a less chopping down might be advantageous. Still, I will say this, in defence of large ingots, that provided they are sound to start with —and I believe it is established that no amount of working will eliminate unsoundness—it does appear possible to make fairly good mechanical stuff of them without any working at all, and simply by a series of heat treatments. I have myself frequently experimented with cast steel, and have obtained quite a forged quality, merely by heat treatment. To go quite to the other side of the argument, I may say that I have come across many forgings for various articles that I would have exchanged without hesitation for good, sound castings—properly heat treated after being rough machined. Mr. Fletcher thinks that the tests required nowadays from the steel maker are very rigid. Possibly; and one good reason is that the march of engineering demands that a pound of steel shall do very many more times the amount of work it did in a given time a very few years ago. However, I would not have Mr. Fletcher and others miss the drift of my paper in this connection.

The intention of the paper is to suggest how the tests can be cut down rather than enlarged, by attempting to establish a relation between the different tests and observations. For, obviously, if the relations be known, and if they are permanent, the simplest and cheapest test reveals all the secrets of the metal's constitution. I tried to show, for example, that the tenside gave an indication or a test result—the extra cost of which was only in the looking for—that for many practical purposes seemed to me rather more illuminating than the other figures from the same specimen. The observance of the tenside did away, as a rule, with the necessity for impact and similar tests and the micro examination, except to the unduly sceptic. On the other hand, either of these less costly tests might on occasion be substituted for the tensile test. I have, nevertheless, freely admitted the imperfections in the relations owing to the host of minor variables which ought not, perhaps, but do exist; so that, in our present state of knowledge, a definitely suspicious indication in one test should be confirmed by some other test.

It is one of the objects of my paper to further the protest that is being made by abler writers than myself, to engineers that their specifications in many cases call for properties that concern them *very little indeed*, and do not necessarily cover those properties which are the life blood of their manufactures. That there are certain laws of probability as to the general qualities of a sample is evident. Such laws, however, indicate the procedure to be adopted in testing, and not a definite verdict of the quality.

I have also endeavoured to enter my protest against the steel maker that the tenacious adherence to one, or, at most, two properties, which, variable as they are, still " show up " the most uniform—a vastly different matter from the thing really wanted—is hardly a practice likely to lead to the required greater all-round uniformity in the properties of the products. With the inevitable increase of work demanded per unit of mass—as only lately exemplified in the motor car, and probably now about to be carried still further in the flying machine—uniformity of the various grades of steel in their respective properties is an unavoidable requirement.

I was interested in Mr. Dudley's remarks about the advance which has been established by press working as compared with hammers. He is unquestionably correct in what he says. Press work does reach to the heart of the metal much more than hammering on the outside. The President has called attention to Mr. Stead's improvement of steel rails by re-heat treatment a few years ago. To a great extent my paper is a re-expression of the same thing, for I believe that many forgings that have now to be rejected might be saved by re-heating; and I know that many forgings are passed which are really in a wicked condition, although to the letter of an inadequate specification.

The fifth meeting of the Session was held at the Institute, Dudley, on Saturday, January 18th, 1908.

The President, Mr. R. BUCHANAN, occupied the chair.

The minutes of the last meeting were read, approved, and signed.

The following paper was then read by Mr. JOSIAH BUTLER, of Swansea.

THE
MANUFACTURE OF CONCRETE BRICKS
FROM
BLAST FURNACE AND OTHER SLAG.

BY JOSIAH BUTLER, M. I. MECH. E.

The important question of the utilisation of the waste material produced by Blast and other furnaces has seriously occupied the consideration of experts for some time past, and it is my intention to deal briefly to-night with a method of utilising this waste material profitably.

In the first place, we have to consider the fact that all the slag made by the present Blast Furnaces costs anything from 4d. to 6d. on each ton of iron produced to convey it to the slag tip, but this cost does not include any sum for rental upon tipping ground. This would mean, for a furnace giving an output of from 800 to 1,000 tons per week, that the cost of removing the slag alone to the slag tip would be about £1,000 per annum.

Owing to the large amount of lime and silica contained therein Blast Furnace Slag is most valuable as a brick-making material.

I propose now to show how, instead of removing the slag to the tip, by running it in its molten state into water, and there granulating it, a first-class material for brick-making is available. The excess of lime contained in the slag causes it to be very easily granulated when brought into direct contact with the water which converts all the free lime into a fixed state, and at the same time diffusing all the free sulphur from the slag. It will at once be seen that the ease with which the slag can be granulated saves a very considerable expense, as no grinding of the material is necessary, as with other slag and dust destructor refuse.

The question of the manufacture of bricks from Blast Furnace Slag has been ably dealt with on the Continent, and great strides have been made in this direction; a great number of plants being now in active operation.

I do not think that I can do better than to give the results of my experience on this subject of the utilisation of Blast Furnace Slag for the manufacture of these concrete bricks.

In the year 1904 a small plant was erected at the Landore Works of Messrs. Baldwins, Ltd., which was capable of producing about 8,000 bricks per day of nine hours, as an experiment. The plant was thoroughly successful, and with a view of proving the value of the bricks for building purposes the whole of the output of this small plant was used in connection with the general construction and alterations at the various works belonging to the firm in South Wales. A few, however, were used for building cottage property. Some of the bricks were used in the construction of four chimney stacks, three at the Landore Works and one at the Cwmavon Works, working on Steel Melting Furnaces and a Re-heating Furnace. The stacks ranged in height from 100ft. to 150ft., by 3ft. to 5ft. square, and are all working on high temperature gases. We also replaced the ordinary quality red brick with this new Slag Concrete Brick in the building of the outer walls of steelmelting furnaces, re-heating furnace construction, boiler settings, and for general building purposes. The whole of this work presented a very fine appearance, and I consider it is certainly an object lesson to all who may have a suitable refuse to dispose of.

This experimental plant consisted of a rough granulating arrangement, a furnace for drying the granulated slag, a conveyor and lime slacking plant, measuring machine and elevators for lifting the mixture to an edge runner grinding pan mill, used for mixing, and serving a pulveriser which fed the brick press from the mixing pan. The press was a vertical one with a revolving table, having a vertical upward pressure on the 4½in. by 9in. face to form the brick, and one steam hardening chamber.

The whole was fitted up with a narrow guage railway with suitable turn-tables to serve the plant. The complete installation was supplied by an engineering firm at Leeds.

The brick produced by this experimental plant has proved so satisfactory as a building material that a much larger plant has been constructed at the Landore Works on a German principle, which is capable of a daily output of from 25,000 to 45,000 bricks. This plant is built on the most modern lines, and embraces every possible labour saving device and special appliances to ensure uniformity of shape, size, and quality in brick. The plant is contained in two buildings; the granulating and elevator plant being erected in one house close to the Blast Furnaces, see general arrangement Fig. 1, and a larger building some distance away housing the following machinery, which is shown by the various drawings herewith.

Lime grinding mill with elevator and dust fan complete, slag hoist, mixing silo, preparing machine, two horizontal brick presses. Three large brick steaming chambers arranged side by side, all served with suitable narrow guage lines and turn-tables for dealing with the brick trolleys to and from brick presses, chambers and railway sidings. See Figs. 8, 9, and 10.

The plant is steam driven by a 90 I.H.P. horizontal engine. The steam for this engine and chambers is supplied from two 7ft. by 26ft. Lancashire boilers, working at 120lbs. pressure per square inch. The following is a description of the plant and the method of working.

With reference to the two horizontal brick presses mentioned above I would point out that these differ somewhat from the presses usually made by English engineers, who provide upon their presses a revolving table working in a vertical form with a delivering arrangement for the new formed brick, and construct the machine in such a manner that the pressure comes directly on the 9in. by 4⅜in. face of the bricks. This gives an area of about 39.4 square inches to receive the total force exerted by the machine. The horizontal press supplied by the German engineers is constructed in such a manner that the total pressure is exerted on the 9in. by 3in. face of the brick, which gives an area acted upon of only 27 square inches. It will thus be seen that by this means a much better chance is possible of obtaining a more solid and less porous brick. The press is also arranged in such a manner that the wear and tear that takes place can be very easily adjusted when necessary. There is no delivering gear necessary other than the attendant who receives the brick from the two moving slides which form the brick mould and pressing chamber.

Another advantage to be gained by pressing the brick upon the 9in. by 3in. face is that the thickness of the brick always remains the same, whereas in other presses it varies considerably, thus causing varying mortar joints in the building upon which these bricks might be employed. The method of pressing is effected by the gradual and even approach of two pistons within a press form. This enables any air which might be in the mixture to easily escape from the two ends, consequently a more solid and less porous brick is the result. This press is shown on Fig. 7.

Many attempts have been made to make a press with the object of turning out more than one brick at a time, but these have not met with much success in consequence of the impossibility of the removal of the two bricks from the moulds at the same time, and also owing to the moulds being generally unequally filled, which would cause the resultant bricks to be of unequal solidity and size.

GRANULATING PLANT.

The granulating is done by running the molten slag into a bosh of water, which is about six times the volume of the slag. (The backwater from furnace and tuyeres and coolers is used for this purpose). The excessive quantity of lime contained in the slag causes it to split up immediately upon contact with the water into innumerable small flakes or shells, and all trace of unspent or free lime is entirely eliminated from the slag after this operation, the free sulphur at the same time being also carried off by the great volume of steam generated in consequence of the intense heat of the molten slag falling into the water.

The slag being thus granulated, it is flushed down a culvert arranged with sufficient fall to enable it to flow easily. (I may say that the granulated slag in this state is very light). The slag culvert empties itself into a receiving chamber arranged at the bottom of the elevator, which is erected at some considerable distance away from the Blast Furnace. The granulated slag is then elevated to a pair of heavy squeezing rollers which separate the water from it and crush coarse particles of slag, should any exist. After passing through these squeezing rollers it is allowed to drop into a hopper truck arranged underneath for the purpose of receiving and conveying it to the stock bunkers in close proximity to the brick works. Figs. 3, 4, and 5 show machinery arranged in house for dealing with granulated slag.

LIME GRINDING HOUSE, ETC.

For the manufacture of bricks from Blast Furnace Slag, white lime has been found to be the most suitable, but this lime must not contain more than ½ per cent. of magnesia. This lime in an unslacked state is put through an ordinary jaw crusher and elevated into a ball mill, where it is ground to a very fine state (See Fig. 10), say to a mesh of 8,000 to the square inch. This ground lime is then filled into measuring bags or boxes which are arranged according to the percentage of lime to be used in the ultimate mixture, and to avoid the possibility of any mistake being made in arriving at the fixed proportions of slag and lime when they reach the proper quarter for mixing. A special point might here be mentioned in reference to the nuisance arising from the fine particles of lime dust floating about in the atmosphere. These particles, unless properly dealt with, become very irritating to the workmen attending to the grinding machinery, and to get over this difficulty a small centrifugal pump has been arranged, and is connected up to the top part of the ball mill chamber. This drains off the floating dust and delivers it into a dust room which is provided with suitable ventilation in the roof.

Having now explained the proportion of the slag in a granulated form, and the method of dealing with the lime, we will at once proceed with the other part of the process.

The slag and unslacked lime in their proper proportions (95 per cent. to 93 per cent. of granulated slag, and 5 per cent. to 7 per cent. of lime) are taken up to the top of the building by means of an elevator hoist as shown on Fig. 9. The mixture is then conveyed by a side tipping bogey to a large hopper or silo, which is capable of holding enough material to make 1,000 bricks. This hopper, or silo, when filled is dropped into a preparing machine, shown on Fig. 6, which is specially constructed with a steam jacketted chamber and containing pulverising blades or paddles, working on the principle of a Root's Blower. The heat generated from the steam jacketted chamber sets up the reaction of the hot lime. This produces in the brick at this stage sufficient hardness to enable it to be handled satisfactorily by the operators of the brick presses and hardening chambers. After this mixture has been thoroughly worked, and the lime has been sufficiently incorporated into the granulated slag, the mixture is let out on to the first floor above the presses, and is there served out to the machines as required, see Fig. 10. These machines press the bricks into their requisite shapes and sizes, and the bricks are then placed on flat-topped trolleys each holding about 700 to 900.

When loaded these trolleys are taken to the steaming chambers, which are each capable of holding, when fully-charged, about 13,000 bricks. The chamber is then closed up and supplied with steam at a pressure of 120lbs. per square inch. The bricks are allowed to remain in this chamber for about 12 hours. These chambers are shown on Figs. 8 and 9.

At the end of this time the steam is turned off from this chamber, and all the steam which is then contained in the chamber itself is blown off as far as possible into the next chamber, which should by this time be standing ready to receive it. The bricks are then taken out of the chamber and loaded into trucks, ready for use, and it will be found that at this stage they are sufficiently hard to endure even rough handling, the steam in the chambers having started the reaction in the lime in a very rapid manner, rendering the bricks capable of being used on any construction immediately they are cold enough to be handled.

As regards the mortar adhering to these bricks, it has been found by actual experience that it is equal to any work done with any red brick quality; in fact, when it has been found necessary to remove any masonry constructed with these bricks after the work has become properly set, considerable difficulty has been experienced in separating them. In order that the joints of any masonry built with these bricks should be the same colour or shade the mortar is made by mixing 5 per cent. of ground lime with the remainder of granulated slag in a mill, which makes an excellent mortar for the purpose, and sets like cement.

UNIFORMITY OF SLAG.

No uniformity of mixture can be expected from dust destructor refuse, because it is essential in the first place to get rid of any material that happens to come along, so that with such possibility of a sudden change in the material with which the furnace is charged any bricks made from this refuse are liable to be of different compositions, and therefore of various colours. This, of course, would be detrimental in either case in a brick suitable for house building. The same remarks would really apply to bricks made from the ground-up slag coming from zinc seconds or slag from zinc retorts, or the refuse from any other metallurgical production. These slags are also liable to be composed of a varying mixture due to the different materials used from time to time in the manufacture of the chief product.

Now Blast Furnace Slag is bound to be somewhat uniform in quality, otherwise the quality of the iron would be affected. Therefore, if the quality of the iron is right, which, of course, is the first object of the blast furnace, it necessarily follows that the resultant slag would be of a grey colour, which would be perfectly suitable for granulating. It will be readily understood that all bricks made from this slag, which is always of a uniform quality, would necessarily be of a uniform colour, which again is a great improvement on bricks made from dust destructor and other refuse slags, which are generally composed of more than one shade or colour.

When using slag of a grey colour and allowing it to run in a molten state into water for the purpose of granulating same, it is found that in consequence of the super-abundance of lime contained therein, the slag will float about in the water and not change its colour; but, on the other hand, if the slag used is of a black colour (which would denote that it still contains a certain percentage of unreduced iron) it will fall to the bottom of the water in the granulating tank, and assume the form of so many pieces of broken glass.

Now the granulated material obtained from the black slag would in course of manufacture require a much larger percentage of added lime to form a suitable Concrete brick. Therefore, in the event of the furnace turning out a black slag, it would be better to take this away to the tip rather than have varying colours amongst the bricks.

PREPARATION OF MATERIAL.

It will be readily understood that one of the most important points to consider in the manufacture of bricks from Blast Furnace Slag is the careful proportion of all the materials that are to be used in its manufacture. It is important to have perfect uniformity in all the materials used, and this must be strictly adhered to, as unless this is done no satisfactory results can be attained. The following are the main points which must always be borne in mind:—

(1). Uniformity of all material to be worked up.
(2). Uniformity in chemical composition, which, of course, controls the chemical action of the lime and slag in the brick.
(3). Uniformity in the thorough slacking of quicklime to hydrate of calcium.
(4). Uniformity in the proportions of lime to granulated slag in the mixture.
(5). Uniformity in the physical properties of the mixture to be pressed, having chief regard to its capacity for lending itself to pressure.

The capacity for complete combination of the materials is dependent entirely upon the mode of preparation of the materials to be employed. It is only by carefully following out and fulfilling the above conditions that a concrete brick plant can be expected to work successfully, for the regularity of the working would vary in proportion to the degree in which any of the above conditions are not complied with. A deviation from any of these foregoing conditions would necessarily cause a corresponding irregularity and possibly an interruption of work, consequently a loss of output.

Since it is possible to manufacture any article in different ways, it is therefore highly essential to always select the best method, and the one which proves the simplest and least expensive, always having due regard to the production of the best possible article.

Now the first two conditions refer solely to the physical and chemical proportions of the crude material, but a careful examination of local conditions must be thoroughly made before answering the question as to the advisability of erecting a Concrete Brick Works.

It must, of course, be first ascertained whether a sufficient regular supply of suitable and uniform quality of slag is available for the purpose of brick-making, and whether the slag can be obtained without difficulty at a normal cost. I may state that the amount of slag required in the granulated form is about three tons per 1,000 bricks made. The lime employed must be, as far as possible, a pure, fat white lime, and must necessarily contain in the slacked condition as high a percentage of oxide of calcium as it is possible to obtain. This percentage should certainly not be under 92 per cent. I may at once state that any admixture of clay or magnesia, which is supposed to impair so-called hydraulic properties to the lime, is decidedly detrimental, and any appreciable quantities of such a mixture would make the lime unworkable.

In reference to the third condition, *re* the slacking of the lime, it must always be borne in mind that we have to distinguish between two methods differing widely from each other.

First, the slacking of lime alone without the presence of granulated or ground slag.

Secondly, the slacking of the lime simultaneously with the mixing of the slag.

If we decide to avail ourselves of the first method, it will soon be seen that a good many advantages which alone are offered in the latter method are entirely lost. One point that has an important influence on the composition of a suitable moulding material is the conversion of burnt lime into hydrate of lime which takes place by 100 parts of burnt lime absorbing 32 parts of its weight of water. This water combines chemically with the lime, and a very considerable heat is generated.

I therefore contend that the process in which unslacked lime is used for mixing with granulated or ground slag is much more suitable in all cases where the granulated slag carries a certain amount of water or moisture. This moisture, however, should not exceed 8 per cent. to 10 per cent., for with the process under consideration this mixture is immediately placed in a steam jacketted preparing machine in which the best results alone can be achieved. Immediately the mixture is made it necessarily follows that the unslacked ground lime commences absorbing moisture from the granulated slag, and heat is at once generated. This process is greatly accelerated by the introduction of the mixture into the steam jacketted chamber, which sets up a rapid reaction even before the brick is made.

It is in this process that sufficient " toughness " is given to the material to allow the resultant brick to be sufficiently hard in its unbaked condition to allow of rough handling, and also to allow the lower tiers to withstand the great weight of the tiers above when placed upon the brick bogeys.

The employment of this steam jacket not only increases the plasticity of the mixture, but also insures complete slacking of the burnt lime, which is a very important point. Another important feature of this steam jacket preparing chamber is that the burnt lime is completely slacked in about five minutes, whereas under ordinary conditions complete slacking of the lime would *occupy anything from* 10 to 20 hours.

As the brick presses work simultaneously there must be sufficient space provided above them to accommodate the material for one charge, and this space is arranged on a stage above the presses upon which the material falls as it emerges from the mixing machine. The mixture is then conveyed to the presses by hand, as owing to its plasticity it adheres to the walls of the entrance shoots which lead to the presses. In order to prevent any interruption in the continuity of conveyance of material to the preparing machine, in consequence of the work being done by charges, the funnel-shaped hopper at the top of the building is capable of holding the quantity required for one charge. The raw material, *i.e.*,slag and lime as mentioned before, is brought up the elevator in tilting bogeys, which can always be uniformly filled with a striking board which would ensure an equal number of bricks at each pressing. It is only necessary to weigh a sufficient quantity of pulverised, burnt lime as is required for a given number of bricks. Each tilting bogey will accommodate sufficient material to make about 250 bricks. The hopper will hold the material from four of these tilting bogeys and the requisite lime. The man in charge of the hopper must take care that with each bogey a bag of lime is tipped into the hopper to ensure the regularity of mixing results.

Providing that this mixture is always regular, it necessarily follows that the duration of the mixing process in the steam jacketted chamber is always the same.

Since the presses always work the material with due regularity, the perfect arrangement of the mixing blades in their action upon the mixture has shown that a period of ten minutes would be sufficient to ensure a proper degree of mixing, but to make doubly sure that the operation of mixing is perfectly accomplished from 20 to 25 minutes should always be allowed for this operation. This ensures that the proper proportion of the material in the steam jacketted chamber is absolutely perfect, and the formation of isolated pellets of lime is entirely avoided, and, therefore, further handling of the material through a crushing machine becomes unnecessary. The structure of the finished brick is so perfect in its formation that no particles of lime can be discerned. Should it be desired to add any colouring matter for the purpose of obtaining a finished brick of a certain shade, such colouring matter can be added at the time of making the mixture.

I would here mention that if the plant is steam-driven, the exhaust from the engine is made use of to heat up the steam jacketted preparing machine, consequently the consumption of steam for heating purposes is a matter that need not be considered as far as cost is concerned; in fact, it will be seen that from many points this machine is a perfect mixer. It is free from intricate working parts which are so prevalent in most machines, and which are always a source of trouble to brick manufacturers. One of the principal features to consider in the manufacture of bricks is the absolute necessity of having machinery which, in case of mishap, is quickly adjustable, and possesses the faculty of being adaptable to all conditions of work to which it might be put.

HYDRAULIC PRESS FOR TESTING.

A noteworthy feature in connection with the new brick plant described is the press for testing the manufactured goods. The ram, or plunger, is arranged so that its area is equal to the 9in. by 4⅜in. face of the brick to be tested, which is always placed upon the ram table with a loose block of iron equal in size on top of the brick. The press is worked by a small ram of 2¼in dia. which is actuated by a ratchet lever, the top of this ram being screwed with ¼in. pitch square thread. Two large 12in. diameter hydraulic gauges are connected to the cylinder to indicate the pressure which the press is exerting on the brick, and each gauge is made to read up to 8,000lbs. per square inch. This apparatus gives the pressure in lbs. per square inch, and immediately shows what each brick will stand, a condition which must invariably be guaranteed, as it is a most important point to know what pressure a brick will stand without breaking. I attach herewith a sketch of the press in section. I have carried out several tests upon various bricks manufactured in this district, and submit the following test sheets for consideration :—

A.

SLAG AND REFUSE BRICK TESTS.

Date of test.	Made by	Material made from.	Age of Brick.	Cracked at	Crushed at	Mark on brick.	Total tons crushing on brick.	Remarks.
				lbs. per sq. in. on brick.				
9/9/07		Zinc Slag and Lime	New made	1000	1200	H	21·3	Just out of chambers
do.		do.	do.	1000	1200	J	21·2	do.
do.		do.	do.	1000	1300	K	22·8	do.
do.		do.	7 months	500	650	L	11·45	Had been out in the weather
do.		do.	7 months	500	700	M	12·35	do.
do.		do.	7 months	550	750	N	13·2	do.
do.	Baldwins Ltd.	Granulated B F. Basic Slag & Lime	40 do.	2000	2200	O	38·7	do.
do.	Landore	do.	40 do.	1300	3100	P	54·3	do.
do.	Baldwins Ltd.	do.	40 do.	2300	2500	Q	43·9	do.

B.

SLAG AND REFUSE BRICK TESTS.

Date of test.	Mark on brick.	Made by	Composition of Brick.	Age of Brick·	Cracked at lbs. per	Crushed at sq. in	Total tons crushing on brick	Remarks.
9/9/07	A.	Baldwin's Ltd.	B.F. Slag and Lime	12 months	1000	2400	42·3	Basic B.F. Slag
do.	B.	Baldwin's Ltd.	do·	9 months	2000	2200	38·8	do.
do.·	C.	Baldwin's Ltd.	B.F. Slag, Lime and Breeze	30 months	1200	3100	54·7	do. (stopped test)
do.	D:		Zinc, Slag and Lime	1 month	300	900	15·8	Ground up Slag
do.	E.		do.	do.	1000	1200	21·1	do.
Nov., 1906	S.		B.F. Slag and Lime from Baldwins Ltd	from steam chambers	2000	2200	38·8	Baldwins B.F. Slag
Aug., 1907	T.		do.	9 months	2200	3300	58·1	do.

C.

ANALYSIS OF CONCRETE BRICKS SHEWN IN TEST SHEET "B.'

	Brick B.	Brick D.
Lime	38·343	11·950
Silica	31·150	53·480
Calcium Sulphide	2·774	
Peroxide of Iron	·176	3·971
Suboxide of manganese	1·842	·156
Alumina	10·413	8·663
Sulphur		·737
Carbon di-oxide and combined water	13·900	19·820

D.

ANALYSIS OF BLAST FURNACE SLAG. (BASIC).

	Ordinary Slag.	Granulated Slag.
Silica	33·900 $^{0}/_{0}$	34·710 $^{0}/_{0}$
Lime	44·060	44·030
Oxide of Manganese	1·909	2·160
Sulphur of Lime	4·160	3·690
Protoxide of Iron	1·160	·800
Alumina	11·600	11·400
Magnesia	3·090	3·106
Total ..	99·879	99·896

ANALYSIS OF SALTS FORMING WHITE DEPOSIT ON BRICK.

Peroxide of Iron	·120%
Alumina	1·020
Lime	3·540
Silica	3·630
Sulphuric Acid	27·802
Soda	18·232
Water	44·600
	99·940

REFERENCE TO TEST SHEETS.

The various tests given upon the sheets herewith show the relative value of ground-up slag as compared with Blast Furnace Granulated Slag as a brick-making material, taking into consideration the age of the brick.

Referring to test sheet marked A, the bricks H, J, and K, also bricks L, M, and N, were made from ground-up slag. The first three bricks were tested immediately they came from the hardening chamber before any reaction due to age had been set up. The bricks crushed at the various pressures indicated, whereas those bricks marked L, M, and N, notwithstanding they had the benefit of seven months' weathering, which should have improved them, sustained a very much less crushing load than the new bricks H, J, and K.

Again, upon reference to test sheet B, it will be noticed that the bricks marked D and E, which in each case were made from crushed zinc slag, and both of which were one month old, yielded under pressure at entirely different strains, viz. :—

"D" at 900lbs.)
"E" at 1200lbs.) per square inch.

This clearly points to the importance of carefully considering a perfect mixture, both chemical and mechanical, with a view to obtaining a finished product that will stand a uniform crushing strain, which should increase according to age, and not be erratic, as in the case above referred to, for it will be seen that in these cases a new brick withstood a much greater pressure than a brick seven months old, being exactly the reverse to the conditions one would naturally have expected.

Again, referring to test sheets A and B, it will be seen that the bricks marked A, B, C, O, P, Q, S, T, compare very favourably one with the other. These bricks were all manufactured from Blast Furnace Granulated Slag, under the new process described by me. Taking into account the various ages of these bricks, it will be seen that in most cases they have certainly improved by age, and the tests also show that this improvement increases with the age of the brick. Even in the case of the new brick S, just out of the steam hardening chamber, it will be seen that these bricks can be made as reliable as the best red brick, both as regards cracking and crushing strains.

Again, referring to test sheet B, and the tests of the two bricks B and D, the analyses given on sheet marked C show the different compositions of these bricks. The brick B, being made from blast furnace slag, carried a small percentage of peroxide of iron and sulphur in a fixed state, whilst the brick D, which was made from ground-up slag from a zinc retort furnace, shows peroxide of iron as 3.971 per cent., which would discolour the brick in patches, and the sulphur as .737 per cent, which is somewhat in a free form, or, in other words, it is combined with something else, which forms part of a soluble salt that is quite capable of being washed out from the brick when it becomes saturated with water. This salt, it might be mentioned, shows itself on the face of the brick both inside and outside of the building, and forms a white deposit which would easily find its way through plaster and paint, and would, therfore, be most detrimental as a building brick for inside partition walls in house property. I have had some of this white deposit analysed, and it was found to contain as much as 10.96 per cent. of sulphur, which appears to be a most distressing feature as regards bricks made from ground-up slag of irregular composition. The same thing would be liable to happen with bricks made from dust destructor refuse, for the amount of lime used in the manufacture of bricks from this material is not sufficient to fix any sulphur that might be present in such material and in such a form.

The analysis of these salts is also given, together with typical slag analyses, see sheet D.

I have given the analysis of the slag taken from the slag shoot when running into the slag ladle, and I also give the analysis as near as possible of the same slag from the same running, in the granulated state suitable for concrete brick-making.

As regards the action of frost on such bricks, it can be safely stated that frost has no effect whatever upon them after the reaction of the lime has been set up. It is sufficient to say that tests have been made by placing these bricks in a freezing chamber direct from the steam hardening chamber, and that they have been there left to freeze for 12 hours. Immediately the bricks were removed from this freezing chamber they were boiled and then frozen again, and even at the end of this most drastic treatment they did not show the least sign of any detrimental effect.

I may say I have very carefully examined the various structures which have been built from these bricks, and have quite failed to find any defect arising from these causes.

E.

SOAKING TEST.

Distinguishing Mark.	Composition.	Weight before. lbs.	Weight after. lbs.	% Moisture to total weight.	Hours Soaking	Age of Brick. Months.	Remarks.
Brick same as O, P, and Q	B.F. Slag and Lime ..	8	8·75	12·5%	50	40	Taken from Stock.
Brick same as H, J, and K	Zinc Retort Slag & Lime	7·437	8·25	10·92%	50	New	do.
Brick same as A.	B.F. Slag and Lime ..	8·25	9	9·09%	50	12	do.
Brick same as G, I. ..	Wire cut Red Brick ..	8·25	9·312	9·58%	50	Burnt Brick	do.
Brick same as T.	B.F. Slag and Lime ..	7·562	8·5	12·4%	50	9	Dried in oven before soaking.
Brick same as H, J, and K	Zinc Retort Slag & Lime	6·312	7·875	24·75%	50	New	Dried in oven after steaming.

F.

BURNT CLAY BRICK TEST.

Date ot test.	Mark.	Total tons crushing.	Composition.	How made	Cracked at lbs. per sq. in	Crushed at lbs. per sq. in	Remarks.
9/9/07	F.	70·5	Staffs. Clay	Pressed	400	4000	Stopped test at 4000 lbs.
do.	G.I.	21·1	Red Brick	Wire cut	250	1200	Used for Chimney Stacks & General Work
do.	G.	35·2	do.	Pressed	200	2000	For Tunnel Work and General Work
do.	R.	30·0	do.	Pressed	300	1700	Used for Chimney Stacks and General Construction.

I have also carried out tests with the object of ascertaining the amount of moisture these bricks can absorb, and I have set out in tabulated form upon sheet E the results of my tests. It will be clearly seen upon reference to these figures that these bricks absorb less moisture as they get older. It also shows that the brick made from Blast Furnace Granulated Slag compares very favourably with ordinary red brick which is used for ordinary building construction, but it will be observed that the bricks H, J, and K, which were made from the ground-up zinc slag, are far from being satisfactory, as the porous condition of these bricks can only be put down to the unsuitable mechanical mixture of the material from which they are made.

In reference to test sheet marked F, it is only necessary for me to point out that this shows the vast difference between the ordinary red clay and the brick made from Blast Furnace Granulated Slag.

Below I beg to submit an estimate of cost for the granulated slag bricks, which I consider compares more than favourable with the manufacture of the ordinary red clay brick, against which the slag or concrete brick will have to compete.

LABOUR COST, PER 1,000 BRICKS.

Men.	Occupation.	Rate.	£	s.	d.
1.	Granulating Slag	4/6		4	6
1.	Lime grinding house	4/6		4	6
1.	Loading bogies at bottom of hoist	4/0		4	0
1.	Discharging Slag	4/0		4	0
1.	Discharging Coal for boilers, etc.	4/0		4	0
1.	Discharging at top of hoist to Silo	4/0		4	0
1.	At preparing machine	4/6		4	6
2.	On Floor above presses feeding machine	4/0		8	0
2.	On presses removing moulded bricks	4/6		9	0
4.	To load moulded bricks on bogies	4/0		16	0
4.	Hardening chambers and discharging	4/0		16	0
1.	Stoker and engine man	6/6		6	6
1.	Foreman	8/0		8	0
1.	Fitter or Blacksmith	6/0		6	0
1.	General labourer and spare man	3/6		3	6
23	Total labour, cost per day		£5	2	6

Say, 25,000 per day.

Therefore $\frac{102 \cdot 5}{25}$ = 4·1/- per 1,000 bricks.

COST SHEET PER 1,000.

Mark.		cwts.	qrs.	lbs.	Rate.	£	s.	d.
A.	Cost town water per 1000 Bks 500 gallons,				-/6			3
B.	Cost coal per 1000 for hardening chamber	2	2	0	15/0		1	10½
C.	,, ,, ,, ,, for steam to engine ..	1	2	0	15/0		1	1½
D.	Cost of lime per 1000, say	4	0	0	10/0		2	0
E.	Cost sundries, stores, oil, wear and tear, etc., per 1000				1/0		1	0
F.	Office charges, rates and taxes, etc., also travelling expenses, etc., per 1000 ..				1/6		1	6
G.	Cost traffic charges, etc., per 1000 ..				-/6		0	6
H.	Depreciation on building and plant, say per 1000				1/0		1	0
J.	Cost Labour per 1000 bricks, say ..				4/1½		4	1½
K.	Interest on £12,000 @ 5% = $\frac{600 \times 20}{300 \times 25}$ ..				1/7½		1	7½
L.	Charge for granulated Slag and delivery of same, say 3 tons @ -/6 ..						1	6
M.	Royalty per 1000 bricks				1/0		1	0
	When making a daily output of 25,000 bricks, total cost per 1,000 ..						17	6

If plant were kept operated night and day, and producing say 45,000 bricks in 24 hours, then the above standing charges would be reduced as follows:—

Office charges, etc.	·832/-
Interest on Capital	·890/-
Depreciation	·570/-
Foreman to have charge of two shifts.. ..	·148/-
	2·440/-

With an output of 45,000 bricks per 24 hours the total cost would be 17·6 − 2·44 = 15/0½ per 1,000.

In conclusion, although it is not expected that these bricks should be capable of resisting the action of fire, yet it can be safely said that they will withstand a much greater heat than the ordinary red brick. In several of the instances previously quoted these bricks have been used for work where they have been exposed to high temperatures without detrimental results. As an instance, in the case of the outer walls of the regenerators of steel melting furnaces, where the thickness was 18in. and 2ft. 3in., only 9in. of fire-brick being used on the inside. In these cases there was less buckling or distortion than with those built in red bricks. Indeed, a case might be cited where some houses were built, the lower portion of concrete brick, and the upper parts of red bricks. Eventually this property was destroyed by fire, and it was then found that the red material was badly twisted and distorted, and had to be taken down and rebuilt, whilst the lower portion, which was built of concrete bricks, remained firm and intact, and showed no detrimental effects from the great heat to which it had been subjected.

The photographs attached show the chimneys and brickworks which have been constructed with these bricks.

Mr. **Butler**, in the course of his remarks, explained that with regard to the lime suitable for amalgamation with the slag, it did not require to be a hard-burned lime. If it was too hard-burned it slaked slowly; and what was wanted was a lime which slaked quickly when it became heated in the hot chamber described in the paper. With reference to various sorts of slags, there was often a disadvantage in using slags from other furnaces than blast furnaces. Some of the bricks specified in the tables of tests were made from ground-up zinc slag, and a curious thing happened, for with regard to the tests H., J., and K. (produced from ground-up zinc slag) these bricks were tested directly they came from the steam chamber, and stood from 1,000 up to 1,300lbs. before crushing, whereas L., M., and N. (which were produced from the same slags), and had had the advantage of seven months' weathering, only stood 650, 700, and 750lbs. to the square inch. It would be seen that this class of material did not improve by age, that was going back, instead of forward, and he mentioned it to show the disadvantage of using slags from other furnaces than blast furnaces. O., P., and Q. stood 2,200lbs. to the square inch, and one of them stood as much as 3,100lbs. per square inch before it crushed. The slag brick or concrete brick had a better bed than the red brick. The brick marked S. was a similar brick to the one shown in the table marked T., having been made by the same machinery. It stood 2,200lbs. per square inch immediately after being taken out of the chamber, whereas nine months afterwards a brick from the same batch, marked T., stood 3,300lbs. to the square inch, thus indicating that the brick gets better by age.

The only difference shown in the slag used for the manufacture of bricks before and after granulation is in the sulphur.

THE DISCUSSION.

Mr. J. **Donechay**: I should like to ask a question. Thirty-five years ago I remember bricks made from slag, but my experience was that they cracked. It is also quite right about the variation of slag. Some slags have 25 per cent. of lime, some 40, some 45, and the last a little bit too much. It occurs to me that if the slag mentioned in the paper contains lime enough to be put into this process, how is it that the lime which is added to it after granulation does not mix with it? My experience of slag in the North of

England was that we used to make mortar from the limey slag ground in a mill, and we used to sell it for building purposes. Then you have to consider whether the brick spoken of in the paper will crack when used for outside purposes. Can the author give us a guarantee that the brick will not crack? Twenty years ago I built a wall with mortar made from slag, and it stood very well for a long time, but the joints are cracking now. The wearing qualities of slag brick seem all to depend upon what sulphur, phosphorus, silicon, and lime the slag contains. If you get a slag very high in some of these elements it will not last. There is great variation in the quality of the slag made at a blast furnace. You will even get different slags in the same ladle, with an immense variation in the percentage of iron. What is to be done with black slag? In the foundry, with a cupola, you simply melt your iron and you know what you are going to obtain, but with the blast furnace it is altogether different. We have to contend with different ores and all the rubbish of various ingredients, gas coke, and all sorts of fuel. These are the troubles we have to deal with in the Midlands. Of course, in the North of England they get regular ores and good fuel, but it is quite different here. I am not criticising the paper adversely, but the whole matter is one which wants thinking about before embarking upon. To sum up, I consider that in the Midlands you have a big question before you, as to making bricks out of the local impure slags.

Mr. JOHN PATERSON (of Workington): I think we are very much indebted to Mr. Butler for this valuable paper. I don't know whether this process will turn out valuable to the Ironworks of this district, but it undoubtedly seems a very profitable matter for our friends at Swansea, Messrs. Baldwins. It appears to me that there are several points which ought to be carefully considered. You have to be almost scientifically correct in all your ingredients before you get a satisfactory brick. I had experience myself with slag brick making many years ago, and have seen a good many thousands of bricks made from slag, and over £50,000 or £60,000 expended in this same business. That money has been lost all through slag bricks. I was not personally interested in the losses, but I was connected with it to a certain extent. In those days the production of slag bricks by mixing with a small proportion of cement was also attempted. What surprised me very much about the paper is the very low cost at which the bricks can be produced. The paper says 45,000 bricks in 24 hours at about 15s. per thousand. Well, even at that figure, I don't think the process would be profitable. I am rather pleased to say that I am not personally connected with blast furnaces at the present time. They are the worry of one's life. I have had about thirty years of it, and therefore I know. I trust you will all take the hints thrown out in this paper and do the best you can with your slag. On the seaboard the utilization of slag is now an important matter, and it is also important, to some extent, in the Midlands. I think we are indebted very much to Mr. Butler for many valuable hints in this paper, and I trust the process will turn out as well as he anticipates. I don't think, however, that slag bricks will stand much heat, though they may be very useful for outside walls and for the building of refrigerating chambers. I have had experience of some bricks which seemed to scale in course of time, but they did not crack or split from the frost. I made one experiment, which I may mention : I ground the slag (produced from the hematite pig iron) and mixed with it a certain proportion of engine ashes, and this answered very well. I built several outhouses and walls with bricks made of this, and they stood admirably. These bricks were allowed to dry under cover for three or four months before being used.

Mr. W. H. CARDER : Referring to the manufacture of slag bricks, I believe Mr. Charles Wood, of Middlesbrough, was at one time actively engaged in the manufacture of such bricks for building houses and for other purposes. It would be interesting to know if those bricks are being made in Middlesbrough now, because I have the impression that all buildings built with bricks which are of a vitreous character are damp. You will find ample evidence of this in all the North-Western bridges and stations. That is one of the reasons why the manufacturers of slag bricks will, in my opinion, be unable to compete with red bricks. As to the cost of production, you will notice that 15s. per thousand is the best price which the author can quote, evidently under the most favourable conditions, with continuous production. But you know that works, as a rule, do not run throughout the 365 days of the year without stopping; no machine has been made that cannot break, and workmen do not work as one would like them to do in order to produce the perfect conditions upon which, apparently, the author's estimates are based. The cost of 15s. odd does not, unfortunately, include any provision for taking away the slag; whilst Mr. Donechay is undoubtedly right in insisting upon the great variation in the quality of slags made, for on a good many days in the year blast furnaces have to use ores not of known or constant qualities. I take it that if on two days a week the furnace went wrong it would increase the cost of brick production by about fifty per cent. That is speaking from a business point of view, and as the present price of ordinary bricks is somewhere about £1 per thousand, I do not think, unless blast furnace proprietors here are able to practically rely upon the constant quality of their slag, that there is a great deal in it, if they can dispose of the slag any other way.

The President : You have heard Mr. Butler's interesting paper, and we have had some interesting remarks from blast furnace men, with whom we must sympathise in their sorry experience of slags of a varying character. I think there is a great deal in what Mr. Donechay pointed out as to the irregularity of quality. It appears to me that works having a number of blast furnaces could probably —or in fact, certainly—employ the process with a greater prospect of success than works with one, or even two, blast furnaces could. There is one great advantage which would accrue if this process were not only feasible but commercially successful; and that is in doing away with the volumes of smoke which are so obvious in ordinary red brick making. There are works of other kinds also darkening the air and blackening the country around, and if the brick makers were to cease contributing their share of smoke it would certainly be a very great blessing, not only for the general aspect of the country, but a great saving in fuel as well. Mr. Paterson mentioned about the scaling of bricks made from slag, and I think one of Mr. Butler's tables shows why that is so. In referring to his soaking test, you will find that the bricks absorb more moisture than the ordinary red brick. If the blast furnace slag brick does absorb more moisture, and the frost comes along, scaling is bound to take place. I think that is the obvious deduction. But we heartily wish Mr. Butler and the process he has shown us to-night every success in making a commercial product of a satisfactory character at a satisfactory price, because it would be a benefit to blast furnace men and to the community at large that this process should be successful in all respects, and I have much pleasure, in the name of the Institute, in asking you to give Mr. Butler a very hearty vote of thanks.

The vote of thanks was carried unanimously by acclamation.

Mr. Butler : I will try to answer the various gentlemen altogether if I can, as some have asked the same question. Well, as regards the cost of a 45,000 brick plant, I have estimated the total to be £10,000. That is to say, £8,000 for the plant and £2,000 for the buildings. I have taken £2,000 for the buildings at two per cent. (that is the depreciation and upkeep), and five per cent. on the £8,000 for the machinery.

As regards the quality of the slag, I don't mean to say it should be too limey, although it would not matter, as the lime is in a fixed or combined state, and would not decrepitate, as all the free lime has been reached by the water during granulation. It might have happened that at the time the analysis was taken the slag might have been somewhat limey, we take the slag as it comes; but if it is a very black slag we send it away to the tip. I mentioned that we send the slag after granulation away to the stock bunkers. The installation is arranged to work with a big stock. The different slags are mixed together, and if we get a mean of, say, three different sorts we can, in that way, obtain a certain amount of uniformity.

I have been interested in making bricks since 1894, and I only remember one or two occasions on which we had to send black slag away to the tip. If there is not sufficient lime in the slag, we have simply to add more. That is to say, a black slag takes more lime to make a suitable brick, as it is to much like broken glass, and not gritty enough, and in consequence more ground lime is required to bind it together.

It is a German syndicate which has started this plant at Landore.

One of the speakers mentioned that he added ashes or breeze to the mixture which he made bricks from, and he found that it made a very suitable brick. I have also added breeze, ashes, and clinker to the mixture, and have had some very good results, and I think the reason for that is that the breeze is gritty, so that there are many sharp corners for the slag and lime to adhere to. If you refer to table "B" you will see that brick marked "C" was composed of slag, lime, and breeze. It crushed at 3,100lbs. per square inch, which was an excellent result.

I have here samples of the slag as it comes from the furnace, which has passed through the granulating process.

There was a point raised during the discussion in respect to what allowance had been made for stoppages and breakages in my estimate. Well, that is not by any means a bare estimate. The plant is quite capable of doing all it was designed for, with due allowance for stoppages, which is in accordance with the output given in my paper. As regards the cost of production, you will find I have put coal at 15s. per ton, but you can often get it for less. I have also put in a charge for the granulated slag, 3 tons at 6d. per ton, or 1s. 6d. But you don't have to pay for slag if you have a furnace, so that 1s. 6d. could be taken off the estimated cost if we look at it from this standpoint. The labour for granulating is small, being only one attendant to look after the machinery. This could be the ordinary furnace slagger.

As regards scaling of bricks owing to frost action. We built a wall in June, 1904, two days after some bricks were made, and they were not put into a hardening chamber, but simply kept under cover for two days. The wall is standing now, and it has suffered no ill effect from frost. It shows no signs of scaling yet,

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and I don't think it will. We put some of these bricks out and exposed them to the action of the frost immediately they were pressed into shape, before the reaction of the lime set in, and they did scale badly to a depth of about ⅛in., but after they had been in the steam hardening chamber that prevented any detrimental effects due to frost action. We have offices, outbuildings, shanties, foremen's offices, etc., which are made of this material, and they are all standing well. I might tell you that the plant can be seen in operation. It only started this week, but it can be seen by appointment with the South Wales Concrete Brick Co., Landore, and I shall also be pleased to show you any of the structures I have referred to, made from this kind of brick. I think there is a gentleman in this room who has seen some of the structures.

A Voice : I only saw them from a distance.

Mr. BUTLER : A plant put down at Barrow-in-Furness made a lot of bricks; some houses were built with them. I saw the partition walls being put in with those bricks at some other cottages.

I do not know what is being done at Middlesbrough as regards slag bricks. I think that if there was any trouble from the causes which have been mentioned it would be due to the materials not being properly mixed and also to an ineffective hardening in the steam hardening chamber.

Mr. CARDER : My impression was that the bricks made by the process at Middlesbrough were put into a kiln, and were not steam hardened.

Mr. BUTLER : I don't think that would be the case, they would fuse if they went into a kiln.

Mr. PATERSON : There are some bricks made up in the North which are fused and then cast into iron moulds, but that is a different process altogether to that Mr. Butler has been describing.

Mr. W. J. FOSTER : With regard to the alleged disintegration of these bricks, due to age, I think we can dismiss that from our minds, because a brick manufactured from granulated slag and mixed with lime would no doubt increase in tenacity with age, and any calcium sulphide would be converted into calcium sulphate, which is practically a cement.

Mr. BUTLER : I would like to say, in conclusion, that I have no doubt whatever about this brick. I only wish I had a few thousands to invest in this process. The people who have built this plant are going to build others. They have come to stay. They have built this plant as an object lesson, and I understand there are others to go down.

I have often heard the saying that the Romans made good mortar. It is stated that they made better mortar than we can make. Well now, as a matter of fact, the Romans made no better mortar than we do. They got the proper materials and mixed them well together, although probably we mix them better because of our modern machinery. They simply mixed the mortar, and they let time do the rest, and that is what we are doing.

Mr. L. D. THOMAS : I am very much interested in this paper, and am greatly obliged to Mr. Butler for coming up from Swansea to read it. I think most of you are condemning a process which you have never seen, and which you know nothing about. You have no right to condemn it. It has been the same story all through, and especially as to every great movement in the iron and steel world; Siemens, Bessemer, Thomas, Gilchrist, and others were all pooh-poohed. They had to go to some other country to bring out their inventions, and when our forefathers saw that it was good, they said " Why could not we have it." Now, I will take you in thought to Cwmavon blast furnaces, where years ago they made miles of coping for walls which stood for generations. They are all pulled down now for improvements. The walls there would be from a quarter-of-a-mile to half-of-a-mile on each side of the road, and the coping of those walls was made of blast furnace cinder. They were put there before I was born, and were as solid as stone after being there for sixty years. Why should not the brick we have heard about to-night be the same. You say you must have a certain class of slag; but you can use what you want, and throw aside what does not suit you. Mr. Butler has got a new process, and because he has got a new process you say it is no good. Now give this process fair play. It is a pity we cannot use up our slag here in South Staffordshire instead of having to cover it with trees. You will find this process will be brought to perfection. They will not give it up until it is finished. Buildings made from this material will stand, and if I go down to Wales again I will make a special journey to see the plant. What I would say to all, in conclusion, is " Don't condemn this process wholesale."

THE PRESIDENT : I think Mr. Thomas is in error in saying that anyone is condemning the process. The paper is read not only for our information, but in order to obtain our suggestions, and I think Mr. Butler will welcome and value the legitimate criticism which has been put forward. We don't, anyone of us, condemn Mr. Butler's paper. We wish the process every success, because if successful it would mean a great thing for the Midlands and for the country as a whole.

The Sixth Meeting of the Session was held at the Institute, Dudley, on Saturday, 21st March, 1908.

The President, Mr. R. Buchanan, presided over a large attendance.

The minutes of the previous Meeting were read, approved and signed.

Messrs. David Hadlington, Harold Richards, William Rose, and Alfred H. Wilkinson were elected members of the Institute.

Proposed by The President, seconded by Professor T. Turner, and resolved that Messrs. James Raybould and Walter W. Pagett be appointed Auditors of the Institute Accounts for the year ended 31st December last.

The President :' I have much pleasure in taking the chair this evening on the occasion of Mr. Stead coming to lecture to us. He requires no introduction by me, as his name and his work are so well known to all people interested in metals, and no doubt to many outside of the metal trades. His subject, " Sulphur and Iron," is one of the very greatest possible moment to all in the iron and steel trades, and without further delay I have pleasure in calling upon Mr. Stead to give us his lecture.

SULPHUR AND IRON,

by

J. E. STEAD, F.R.S., Middlesbrough.

Mr. J. E. Stead: The question is whether I shall give a lecture or give a "talk." I fancy you would prefer having a descriptive talk. Carnegie, on one occasion when he was giving a presidential address to the Iron and Steel Institute, stated that the man who reads from a paper speaks from his head, but the man who talks without his paper speaks from his heart. Now I prefer to-night to speak from my heart, and I think altogether it will be better for you. As a matter of fact, I have got such a lot of illustrations to this paper, illustrations which it is impossible to reproduce unless some very generous person will hand over about £100 for the purpose, that I prefer to give these illustrations here to-night by the lantern, and also by means of the sketches which you see on the walls, and by the actual samples on the table before me, and to describe them verbally to you, as you will not have all of them when the paper comes out. When you get the paper in a printed form, in the usual way, it will deal with the matter generally, and you can quietly read over the matter, and you will then, I think, more fully understand the subject I am going to speak about to-night. If you refer to the syllabus which has been distributed you will see that there are eleven items. Each heading is quite sufficient for a lecture in itself. In fact, some of the subjects might be spun out into several lectures. I promised my friend, the Chairman, last year to come here to-night, but I have been so terribly busy that I have hardly had time to get everything quite ready for you. The material is, however, all written except about half-a-dozen pages, and that will be in the hands of your secretary presently. If you will refer to the syllabus you will find among the various items referred to is one called "Auto-Sulphur-Printing by the Baumann Method." Now this simple method is being used regularly in most up-to-date steel works for detecting how the elements, and particularly sulphur, are distributed in steel itself, but up to the present I do not think that anybody has practically applied the method to pig iron.

Mr. Stead then took prints of pig iron sections by this method, pointing out that the result was that the sulphur areas came out coloured dark, while the sulphurless areas remained colourless (see paper). He performed numerous other experiments, and threw a large number of views on the screen illustrative of his subject, the chief features of which are indicated in the following paper.

There has been much written about the metallurgical relations of Sulphur and Iron and other elements, but there is more to be learnt, and many avenues open for research. One cannot read any of the papers which have already been published without seeing that our knowledge is far from complete.

In the remarks which follow I briefly state some of the conclusions of authorities who have studied the subject, and afterwards discuss the question under the following headings, viz. :—

Alloys of Iron and Sulphur.
Alloys of Iron, Sulphur and Carbon.
Alloys of Iron, Sulphur and Silicon.
Alloys of Iron, Sulphur and Manganese.
Segregation of Sulphur in Steel and Cast Iron.
Auto-Sulphur-Printing by the Baumann method.
Does Sulphur diffuse in and through Steel?
Notes on the Elimination of Sulphur from Iron and Steel.
Sulphur-bearing minerals in iron-making materials.
Methods of removing the Sulphur-bearing materials.
Relative harmfulness of Sulphur-bearing minerals in Iron Ores.
Regular working of the Blast Furnace.
Conclusion.

HISTORICAL NOTES.

(a) On the authority of Percy[1],* Iron Sulphide is not decomposed at the highest heat obtainable in a wind furnace.

(b) Iron Mono-Sulphide dissolves in Iron in variable proportion.

(c) Iron Sulphide, at high temperatures, is decomposed by steam :—

$$3FeS + 4\,H_2O = Fe_3O_4 + 3H_2S + H_2$$

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* The small index figures refer to the Bibliography, page 124

(d) When molten cast iron containing 3 per cent Carbon, or less, is treated with Sulphur, the Sulphur combines with some of the Iron, and the combination floats up as Iron Sulphide to the surface of the metal; the Carbon is concentrated in the metallic portion, and in this way it is possible to make white iron into grey.

(e) By heating a white iron containing 0.78 per cent. Sulphur to whiteness more than half the Sulphur was eliminated.

(f) It was apparently Caron[1a] who first found that when Manganese is added to Sulphurous Cast Iron an elimination of Sulphur was effected.

Campbell[2] and Arnold[3] advanced experimental data which appeared to indicate that Oxysulphide of Iron was capable of diffusing through solid steel at 1200°C.

H. Le Chatelier[4] and M. Ziegler[5] put forward results of experiments which appear to indicate :—

1. That there are no Sulphides containing less Sulphur than the Mono-Sulphide.
2. That the fused and solidified mixtures of Iron and Mono-Sulphide are simple mechanical mixtures of these bodies, but that traces of Sulphide may be in solid solution in the iron.
3. That Iron and Sulphide are mutually soluble in all proportions, and when the melted mixtures solidify they do not separate into conjugate solutions.
4. That the so-called Oxysulphide of Iron is a eutectic mixture of Oxide of Iron and Mono-Sulphide, and is not a chemical compound, and that by heating the Oxysulphide to 1500°C apparently the eutectic is removed, from which it may be inferred that the Oxide of Iron acts upon the Mono-Sulphide of Iron at high temperatures.
5. That liquid Oxysulphide does not diffuse through solid steel.
6. That expansion of Sulphide of Iron under the influence of heat is not uniform, for, at about 100° and 200°C the dilatation undergoes considerable disturbance. It expands until 120°C is reached, to the extent of 0.09 per cent., it then contracts with rising temperature to its original volume at 190°C, and contracts to the extent of 0.06 per cent. at 240°C.

They also found a coincident disturbance in the electrical resistance at 130°C to 150°C. The resistance increased up to about 130°C and remained constant up to 330°C. They conclude that their results are positive evidence of dimorphic change.

7. On heating Iron pyrites to 1200°C Sulphur was expelled, and Ferrous Sulphide remained, but on heating to 1500°C about half the Sulphur was volatilised, and the cold mass then consisted of a ground mass, or matrix, of Sulphide of Iron, in which crystallites of Iron were embedded. The forms of these crystallites were sometimes found with hexagonal symmetry, which they consider appears to indicate that Iron in its stable variety at a high temperature belongs to the rhomboidal system, and not to the cubical system.
8. They found that Manganese Sulphide in metallic Manganese was in the form of well-formed crystallites, and concluded that its melting point must be higher than that of Manganese and Iron, and much above that of Sulphide of Iron.

Many authorities have proved that Sulphur is very liable to segregate in steel.

Massenez[6] discovered that when sufficient Manganese is present in Pig Iron containing Sulphur a considerable proportion of the latter separates and floats upwards to the surface, and Sulphur is, in this way, eliminated from the metal.

Saniter[7] discovered that by making a very basic fluid calcareous slag, by the agency of Calcium Chloride, or Fluor Spar, Sulphur can be eliminated almost completely from Steel in the basic open hearth furnace.

I[8] have shown that the great elimination of Sulphur in the puddling process is mainly due to the solvent action of basic silicates of Iron on the Sulphur in the metal, but whether the action is on the dissolved sulphides or on the Sulphur itself is not known.

Andrew Blair[9] and Porter W. Shimer[10] have separated from grey Pig Iron a Sulpho-Carbide of Titanium of the following composition, viz. :—

	Per Cent.
Titanium	62.82
Iron	1.82
Carbon	9.82
Sulphur	22.64
	97.10

The compound separated was in the form of brilliant golden hexagonal scales. This Sulphide, it was shown, escaped the *ordinary methods* for the determination of Sulphur.

I[12] have, by fractional solution of Steels and Pig Irons containing Manganese and Sulphur, proved that these elements are associated as Manganese Sulphide (MnS) in the cold metals.

I have also proved the following chemical reaction :—

$$FeS + Mn = Fe + MnS$$

ALLOYS OF IRON AND SULPHUR.

To call compounds of metals and non-metallic elements—alloys, is in conformity with the practice of French and American Metallurgists[13]. In this country we have usually confined the word " alloy " to metallic compounds, or such mixtures as contain only a minute quantity of the non-metallic elements. Phosphor-Bronze, for instance, is certainly called an alloy by Britishers, and it contains as an important constituent the non-metallic element—Phosphorus. Judging, however, from the internal structural constitutions of the melted and solidified mixtures of metals and non-metals, which most closely resemble those of many of the alloys of metals only, I think it is desirable to class all such mixtures of metals with metals and non-metals as alloys.

Confirming the work of Chatelier[4] and Ziegler[5] I find that Sulphur and pure Iron alloy together in every proportion. When melted they are in solution, and are quite homogeneous, but when cooling, the Iron crystallises in advance in the form of octahedral crystallites, and the last part to freeze is Sulphide of Iron. The illustrations—photos 1, 2, 3, 4—are taken from sections of alloys containing the following, viz. :—

	1 Per Cent.	2 Per Cent.	3 Per Cent.	4 Per Cent.
Iron	88.45	76.9	52.70	10.00
Sulphide of Iron	11.55	23.1	47.30	90.00
	100.00	100.00	100.00	100.00
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Sulphur	4.2	8.40	17.30	32.7

ALLOYS OF IRON, CARBON, AND SULPHUR.

Sulphur and Carburised Iron do not so readily combine; indeed, by blowing Sulphur vapour through molten American Washed Iron (containing 3.5 per cent. Carbon and no Silicon) at a temperature of about 1300°C the maximum amount of Sulphur which the metal would monopolise was under 4 per cent.

The following results were obtained by melting together 100 per cent. American Washed Iron 40 per cent. Iron Pyrites :—

	Washed Iron. Per Cent.	Washed Iron and Pyrites. Per Cent.
Carbon	3.50	3.18
Silicon	Nil	0.28
Sulphur	0.02	3.23

The slight amount of Silicon in the mixture was no doubt derived from the sides of the Silica crucible.

The following results were obtained by blowing Sulphur vapour through Washed Metal :—

	Per Cent.
Carbon	4.04
Sulphur	3.97

There was a large amount of Sulphide of Iron formed by the action of the Sulphur on the Iron, and this was found on the top of the cold alloy.

The Carbon was concentrated in the metal, hence the increase from 3.5 per cent. to 4.04 per cent.

The Photos Nos. 6, 7, 8 illustrate the structure of the metal before and after sulphurisation. They might be taken as being entirely different metals.

In the Washed Iron the eutectic shown is that of Carbon and Iron. The octahedral crystallites of Iron containing some Carbon were the first to fall out of solution, whereas the Sulphur Iron Carbon alloy structure leads directly to the conclusion that, when solidifying, the massive plates of Carbide first fell out of solution, and that the portion last to freeze was eutectic in character, and was a mixture of Carbide and Sulphide of Iron.

When making mixtures of Iron containing less and less proportions of Carbon, with Sulphide of Iron, the Sulphide mixture which floats on the surface becomes more and more highly charged with Iron. This is what would naturally be expected, for Carbon has an attraction for Iron, and the less there is present the less Iron it holds.

In order to ascertain whether the alloys containing between 11 and 90 per cent. Sulphide of Iron, referred to on Page 6, would separate into conjugate solutions when heated with Carbon, each of them was heated to whiteness in retort Carbon lined crucibles, but as Retort Carbon from Gas Works contains some siliceous matter, as might be expected some of the Silica was reduced and passed into the metal, as is shown by the following results, viz. :—

	1 Per Cent. 11 FeS.	2 Per Cent. 23 FeS.	3 Per Cent. 47 FeS.	4 Per Cent. 90 FeS.
Carbon	2.70	2.65	2.65	No
Silicon	3.24	3.59	5.80	metal
Sulphur	1.22	1.19	0.92	separated.

In the case of 1, 2, and 3, conjugate solidified solutions were obtained.

The Sulphides which floated and solidified on the top of the metals were of the following composition, viz. :—

	1 Per Cent.	2 Per Cent.	3 Per Cent.	4 Per Cent.
Sulphur	30.85	30.66	32.46	31.13
Iron	68.00	68.10	66.60	67.60
Silicon	0.05	0.04	0.04	0.47
Not determined	1.10	1.20	0.90	0.80
	100.00	100.00	100.00	100.00

	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Iron Sulphide	84.86	84.31	89.26	85.61
,, dissolved	15.14	15.69	10.74	14.39
	100.00	100.00	100.00	100.00

These results do not indicate the effect of Carbon alone, but the combined effect of Carbon and Silicon. They show that practically the whole of the Sulphide of Iron is expelled under the conditions of experiments Nos. 1, 2, and 3, but that no separation occurred when the mixture smelted contained less than about 68 per cent. of Iron.

Further trials are in progress to determine the effect of Carbon alone, and these will be presented in a communication next session.

ALLOYS OF IRON, SULPHUR AND SILICON.

Turner[14] has proved that Silicon has power to expel Sulphur from Iron.

He found, on melting a metallic substance containing much Silicon and Sulphur, that it split up into conjugate layers :—

	Metallic Substance Melted. Per Cent.	Metal Separated. Per Cent.	Sulphide Separated. Per Cent.
Sulphur	10.93	1.46	22.14
Silicon	10.15	13.45	5.55
Iron			72.27
			99.96

The substance floating on the surface I calculate contained :—

	Per Cent.
FeS	60.95
Fe and Si dissolved	39.05

This 39.05 per cent. would contain all the Silicon or 5.55 per cent., and 100 parts would contain :—

	Per Cent.
Iron	85.9
Silicon	14.1
	100.0

The metal contained 1.46 per cent. Sulphur, and this would combine with

$\frac{7 \times 1\cdot46}{4} = 2\cdot55\%$ Iron, yeilding $2\cdot55 \times 1\cdot46 = 4\cdot01\,\%$ FeS.

The metal separated from this Sulphide would contain

$$\frac{13\cdot45}{100-4\cdot01} = 14\%\text{ Silicon.}$$

These figures are significant, as they enable us to conclude that under the conditions of Professor Turner's experiment the substance which floated on top was a saturated solution, when liquid, of Silicon Iron containing about 14 per cent. Silicon, and that the liquid metal was a saturated solution of Sulphide of Iron in Silicon Iron containing about 14 per cent. Silicon.

	Metal. Per Cent.	Sulphide. Per Cent.
Silicon Iron with 14 per cent. Silicon ...	96.00	39
Sulphide of Iron	4.00	61
	100.00	100

No note is made as to whether there was any Carbon present in these conjugate solutions.

As Turner's results appear to indicate that the Iron alloy containing 14 per cent. Silicon can only admit of the presence of about 1½ per cent. Sulphur, it seemed desirable to determine whether, or not, a large quantity of Silicon would have a more potent effect in eliminating Sulphur.

It is almost certain that Fe_2 Si is a definite chemical compound. This contains 80 per cent. Iron and 20 per cent. Silicon.

Cold alloys containing 20 per cent. Silicon do not usually contain more than traces of Carbon, but as the Silicon is reduced the power to retain Carbon is increased, and more and more Carbon is found in the lower Silicon alloys.

If white Swedish Iron containing 4 per cent. Carbon is melted with Silicon so that the melted mixture contains 20 per cent. Silicon, and is allowed to cool very slowly, the whole of the Carbon will be found on the surface of the metal, or in the blow hole cavities, and none will be in combination in the metal.

An experiment was therefore made in my laboratory to ascertain whether an excess of Silicon would have a similar effect on Sulphur, that is to say, to expel the whole of it from Iron. For this purpose an Iron containing :—

	Per Cent.
Carbon	3.164
Silicon	0.28
Sulphur	3.23

was crushed and mixed with an equal weight of Silicon alloy containing 50 per cent. Silicon, and the mixture was melted in a clay pot. The pot when broken was found to contain a well-fused white Iron covered with a grey powder and a matted, felt-like layer of perfectly pure Silica. The grey powder yielded Sulphuretted Hydrogen gas on treating with acid. It was a mixture of Sulphide and Silica.

The metal mixture before and after melting had the following composition, viz :—

	Before Melting. Per Cent.	After Melting. Per Cent.
Carbon	1.58	Nil
Silicon	25.14	21.84
Sulphur	1.62	0.08

As was anticipated, the result shows that both Carbon and Sulphur are expelled by adding sufficient Silicon to produce the definite compound Fe_2Si with the Iron.

The grey powder and the pure layer of Silica are reserved for further examination. The latter under the microscope appeared to be in the form of beaded hair-like threads. How they assumed that form is difficult to explain.

ALLOYS OF IRON, SULPHUR, AND MANGANESE.

It has long been known that Manganese is one of the essential constituents of Steel, and that it plays a dual part. It is useful in de-oxidising the Steel when in a fluid state and in reducing the red-shortening effect of Sulphur. It was not really known exactly in what way it removed the evil effect of Sulphur until the microscope and careful chemical research were applied to the investigation of the subject.

Arnold[15] found that when there was sufficient Manganese in Steel the Sulphur was observed to be combined with the Manganese.

By careful fractional solution of steel drillings in hydrochloric acid I[16] found that the compound was actually MnS, and also conclusively proved by melting Sulphide of Iron and Ferro-Manganese together, and analysing the product, that under such conditions the chemical reaction was as follows, viz :—

$$\mathrm{Mn + FeS = MnS + Fe.}$$

It has further been found that whilst Iron Sulphide readily dissolves Iron at comparatively low temperatures, Iron is not soluble in Manganese Sulphide at much higher temperatures, and MnS has a very high melting point. It is obvious, therefore, how it is that Sulphide of Iron may lead to red-shortness in Steel. This compound is found in the cold metal around the crystals in irregular globules. These, at 1000°C or 1100°C, melt and dissolve some of the Steel surrounding them, making relatively larger volumes of liquid, and the Steel being necessarily broken up at short intervals throughout its mass by small masses of substance possessing no coherence, it readily falls to pieces or breaks up at the forge. It is exceedingly difficult, however, to obtain de-oxygenated metal free from Manganese and rather high in Sulphur on which to experiment, and one can never tell exactly how much of the red-shortness, in say blown converter metal, is due to Oxygen and how much to Sulphur.

Manganese Sulphide, as was first shown by Arnold, is of a turtle dove colour, and is easily identified under the microscope.

On heating polished sections until they assume a deep purple colour the Sulphide particles then appear pale yellow, or nearly white, on a dark ground, and can readily be photographed.

Manganese Sulphide appears to be quite plastic at the forging temperature of Steel, and is drawn out into threads or flattened into plates without being broken up. On this account the shape of the Manganese Sulphide in Steel, as seen under the microscope in polished sections, enables one to determine approximately whether the Steel has been forged or not, and if forged the nature of the forging—whether rolled into plates or long bars, and an idea as to the extent of the work put upon the Steel.

Photo No. 17 shows a slag and Sulphide of Manganese inclusion in Steel which had been forged. The Sulphide is represented by the parts in half-tone and the slag by the darker parts.

The Sulphide particles are elliptical in section, the length as compared with the breadth giving an idea as to the extent of the work put on the metal. Had the work been much greater the Sulphide patches would have appeared as torpedo-shaped or thread-like extensions.

The same photograph indicates that whereas the Sulphide has not broken up, the slag in which it is embedded was not malleable and has been crushed during the forging process.

In using this method of research it must not be forgotten that whilst the particles of Sulphide are generally more or less globular in form in the ingot or casting, they are not all globular, and only after measuring a number of the Sulphide areas in forged steel sections is it safe to form any conclusion.

SEGREGATION OF SULPHUR IN STEEL AND CAST IRON.

Sulphur, Phosphorus and Carbon are liable to segregate together in Steel ingots and castings, but whilst Sulphur segregates, the Manganese, which it is often assumed is in chemical combination with the Sulphur in the liquid Steel, does not segregate. The researches of many metallurgists have shown that the Sulphur may be three or four times as great in the upper central axis of a Steel ingot as it is in its envelope, whilst the Manganese is practically the same in both places. We are obliged to conclude, therefore, that when Sulphur, Iron, and Manganese are together in solution, the Manganese and Sulphur are not combined as MnS, but that they do combine close to or at the point of solidification. This view is in conformity with the modern theories of solution. If the melting point of the Iron is reduced by the adition of Carbon, etc., the Sulphide of Manganese forms before the metal becomes solid, and separating in the solid or plastic state—being specifically lighter than the liquid metal—it floats upwards and escapes to the surface, or is imprisoned or entangled in the upper layer of metal if this layer solidifies before the Sulphide has reached the surface. In such a case the Sulphur and Manganese segregate together. It is for this reason that the greatest amount of Sulphur and Manganese is always found near the upper part of basic Pig Iron and large Iron castings.

The behaviour of Sulphur and Manganese in Steel and Cast Iron requires much more investigation.

AUTO-SULPHUR PRINTING BY THE BAUMANN METHOD.

Mr. R. Baumann[17] has described a method for revealing Sulphur areas in steel sections. This method, depending on the action of Sulphuric Acid on a Silver Salt, is described by him in the following terms, viz. :—

" A small piece of Silver Bromide paper, such as is used by photographers, is moistened with dilute Sulphuric Acid, and the superfluous liquid is removed. It is then applied to the surface of the metal, which must have been filed smooth and polished, and freed from oil and grease. After remaining in contact with the metal for a short time the paper is withdrawn. The Sulphur areas are coloured dark, whilst the Sulphurless areas remain colourless. The print can then be fixed and washed in the usual manner."

In this description sufficient detail is not given for working the process. In actual practice I have found that a 3 per cent. solution of strong Sulphuric Acid in water gives the most satisfactory results.

Preferably, smooth surface Bromide papers are desirable. These are soaked in the Sulphuric Acid water, and when still dripping wet the glazed or sensitised side of the paper is placed and evenly pressed upon the polished metal surface in such a manner as to avoid the imprisonment of any air bubbles. The print is then removed and washed with water to remove Sulphuric Acid, and finally the excess of Silver Salt is dissolved out with Sodium Hyposulphite. The print is again washed with water to free from Sodium Hyposulphite, and it is then ready for mounting. It is only after a little practice that a good even print can be obtained free from white areas, due to the imprisonment of films of air.

Through the courtesy of Mr. Foster, of the Darlaston Furnaces, I have been supplied with specimens of All Mine Pig Iron produced under his control, and from these after polishing the complete sections, prints were obtained in the manner described.

ALL MINE FOUNDRY PIG.

	1	2	3	4	5	6
Combined Carbon	0·045%	0·355%	0·365%	0·050%	0·365%	0·910%
Graphite ...	3·490	3·270	3·435	3·390	2·870	2·335
Manganese ...	0·490	0·804	0·677	0·490	0·345	0·403
Silicon ...	3·360	2·847	2·586	2·613	2·269	1·605
Sulphur ...	0·022	0·033	0·040	0·113	0·133	0·218
Phosphorus ...	0·335	0·313	0·325	0·390	0·433	0·353

The prints themselves were put before you and reduced photo prints are appended.

They show varying shades of colour, the lightest for the lower and progressively darker for the Pig Irons higher and higher in Sulphur.

Prints are also given from Cleveland Pig Iron—Ormesby Brand—which compare fairly well with those of the Staffordshire qualities.

When Sulphur is exceedingly low in Pig Iron the prints do not indicate any segregation, the Sulphur evidently being uniformly distributed throughout the mass. When it increases above 0.05 per cent, evidence is obtained that the brown stains corresponding to Manganese Sulphide—the compound in which Sulphur is always found in Pig Irons containing sufficient Manganese—appear in the form of what look like imperfect octahedral skeletons, which are most distinct in No. 4 Darlaston Pig Iron, but are also in evidence in many of the other Pig Irons. These skeleton octahedral forms indicate sufficiently clearly that it was Sulphide of Manganese which crystallised in advance of the Carburised Iron itself.

In the print from No. 4 Foundry Ormesby Pig Iron a very remarkable result is seen. The Sulphides here are not uniformly distributed. The lower central area in the print is much lighter than the other parts, but immediately above this is a ridge darker than the average. It is not difficult to form an hypothesis as to what had occurred during the solidification of the metal. The probability is that the Pig was fairly hot, that it solidified tolerably rapidly from the top downwards, that the lower central part remained the longer time in the fluid condition, that during this quiet period Manganese Sulphide crystallised in the liquid metal, and being specifically lighter than the metal itself, floated upwards until it became imprisoned in the plastic solidifying metal immediately above it.

Photo No. 13, No. 4 Forge Ormesby Pig Iron, indicates a somewhat unique distribution of the Sulphides, for in this case, instead of octahedral crystallites—present in the Staffordshire No. 4—the Sulphur has been distributed in quite a different manner. The dark spots over the face of this Pig Iron represent irregular and segregated particles of Sulphide of Manganese. The interpretation of this peculiarity appears to me to be as follows, viz. :—

That this particular Pig was evidently run into the mould at a comparatively low temperature, that the Manganese Sulphide had crystallised out in the metal when it was still passing along

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Prints were actually made and exhibited at the Meeting, the time occupied in their production being not more than two minutes.

the mould in a plastic state, that the crystallites were also plastic and joined each other and were rolled into the round particles actually present.

An examination of the Sulphur print from the head of a Steel ingot, which contained about 0.04 per cent. Sulphur, shows with perfect clearness that the crystallites which first fell out of solution consisted of Steel free from Sulphur, and that it was the Sulphide of Manganese which solidified at a later period, the particles being distributed between the branches of the pure crystallites of Steel. A further proof of the manner in which Sulphur is imprisoned in the crystals of Steel is shown in photo No. 9.

On examining the portions of a print (photo No. 11) representing the central axis of the same Steel ingot it will be seen that the Sulphur particles are not evenly distributed, but follow a curved course, verifying the conclusions of Professor Howe[18], and described in his paper on Segregation and Piping in Steel Ingots, wherein it is stated that during solidification of the central column the Steel makes bridges across from side to side, and that during the contraction of the metal these bridges sink down as shown in the auto-prints.

There is no evidence that the Sulphide of Manganese crystallises in advance of the Steel itself, differing in this respect from what evidently occurs in Pig Iron.

Photo No. 20 shows the irregular way in which Sulphur is sometimes distributed in Steel rails. The central axis, it will be seen, is practically free from Sulphur, but round this axis there is a dark fringe, representing an area of high Sulphur content, whilst the external envelope has the Sulphur in it fairly equally distributed.

Before terminating this section it should be remarked that it is now universally recognised that Sulphur, Phosphorus, and Carbon are always associated together in the last portions which solidify in Steel ingots; that in these portions it is Sulphur which is found segregated to the greatest extent, and that, therefore, when areas high in Sulphur are detected it may be perfectly certain that they are also high in Phosphorus, but for reasons I have advanced in a previous paper may, or may not, be high in Carbon in the cold Steel. They certainly were high in Carbon when at the point of solidification.

DOES SULPHUR DIFFUSE IN AND THROUGH STEEL?

In consequence of the divergence of opinion expressed by authorities in this and other countries on the question as to whether Sulphide of Iron and Oxysulphide of Iron can diffuse through solid Steel at temperatures above 1000°C, it was considered desirable that an experiment should be made on the lines I suggested when discussing one of the latest papers on the subject.

In order to make such a trial, Mr. Driver, of the Birmingham Small Arms Factory, kindly provided me with a gun barrel bored to within half-an-inch of the thick end. The barrel was 36 inches long and 1½ inches diameter at the breech. The Steel for about six inches from the base was embedded in silver sand in a tall crucible. Ten grams of Oxysulphide $FeS_4 + Fe_3O_4$ were placed in the lower end of the barrel, and over this a wad of asbestos. The breech end was heated in a Fletcher's furnace to 1200°C for an hour. It was then allowed to cool, and was removed from the furnace. The enveloping sand was not discoloured, excepting where oxidation of the Steel had occurred.

The asbestos wad was saturated with Oxysulphide of Iron, which had crept up the sides of the barrel for a distance of six inches, and none had penetrated the Steel. During the heating it was noticed that there was a steady evolution of gas.

By attaching the cold end of the barrel to a gas receiver the actual volume of gas given off during the heating was obtained. This amounted to about 90c.c. in one experiment when using almost pure sulphide containing little oxide, and 200c.c. in another when the oxide of Iron was greater in proportion.

The gases on analysis proved to be mainly Carbon Monoxide, and considering the fact that the volume actually given off from the Steel was many times the volume occupied by the Oxysulphide, it is clear that had the latter substance been absolutely imprisoned in the Steel and had had no opportunity of passing out during the heating, the pressure must either have burst the cylinder or greatly expanded the containing vessel.

The auto-print of the vertical section which is appended (photo No. 14) clearly shows that in the solid Steel itself there is no evidence of Sulphur having passed through it. The results of this experiment speak for themselves, and it is hardly necessary to further discuss them. They conclusively prove that Oxysulphide of Iron does not diffuse through Steel at a temperature of about 1200°C.

NOTES ON THE ELIMINATION OF SULPHUR FROM IRON.

As stated on page 5 I have shown that the Sulphur in the puddling process is removed from the Iron by simple solution. The fused Oxides of Iron have a greater solvent power for Sulphur or Sulphides than the Iron itself at the temperature employed, and as a consequence, even when puddling Iron with 0.5 per cent. Sulphur at least 90 per cent. is removed, so that the puddled Iron contains only 0.05 per cent. or even less.

Sulphur in large quantities may be removed from liquid Iron by keeping it in constant contact with calcareous slag and Carbon. It is under this condition that Sulphur is removed from Sulphurous liquid Iron which may have been formed in the melting zone of the blast-furnace.

The metal falling in drops over coke, lime, and calcareous slag gradually loses its Sulphur.

If the initial zone of melting is near the twyers the distance the impure metal has to travel is short, and it reaches the well before the Sulphur is substantially removed, whereas when the melting zone is high up in the furnace the reverse is the case.

The higher the melting zone the more highly calcareous will the slag become before the zone of combustion is reached, for an elevated melting zone is co-incident with a relatively high temperature at the combustion zone, and a calcareous slag is favourable for the removal of Sulphur from Iron.

Judging from laboratory experiments it is almost certain that if sulphurous liquid Iron could be sub-divided into exceedingly minute particles and be brought in that condition into contact with a sufficient quantity of fluid and exceedingly calcareous slag, there would be an almost instantaneous removal of the Sulphur from the Iron, and the Sulphur would appear in the solid slag as Calcium Sulphide, CaS. Solution of the Sulphur in the Slag is facilitated in proportion as the Silicon, Carbon and Manganese are increased in the liquid iron, for the solvent power of Iron for Sulphur is reduced with increase of these elements. The reactions would probably be as follows :—

With Carbon.

$$C + S + CaO = CaS + CO.$$

The Carbon in this reaction, unless supplied extraneously, would be derived from the Pig.

With Silicon.

$$Si + S_2 + (CaO)_2 = SiO_2 + (CaS.)_2$$

With Manganese.

$$\begin{aligned} &\text{1st.} \quad Mn + S &&= MnS \\ &\text{2nd.} \quad MnS + CaO &&= CaS + MnO \end{aligned}$$

This reaction could only take place if the temperature of the metal fell below the point at which the Sulphide of Manganese passed out of solution from the Iron. If it were higher than that temperature, it is almost certain that the Carbon reaction would *occur instead.*

There is no evidence to prove that at high temperatures, say 1600 to 1700°C Manganese itself facilitates the removal of Sulphur from Iron or Steel.

In the steel furnace, in proportion as the Carbon and Silicon are reduced, and the temperature of the metal is raised, more Lime must be present in the slag to enable it to dissolve out the Sulphur from the Iron.

It was in view of this fact that Saniter increased the basicity of the slags in the basic hearth furnace by adding to them the solvents Calcium Chloride and Fluor Spar and excess of Lime, and in this way was enabled to desulphurise when the Iron was at very high temperature, free from Silicon and containing very little Carbon.

It will be gathered from the foregoing remarks what are really the conditions favourable for Sulphur elimination.

Fluid basic Silicates of Iron dissolve Sulphur from fluid crude Iron at temperatures between 1150 and 1300°C.

Manganese added to crude metal at similar temperatures causes an elimination of Sulphur by the formation of Sulphide of Manganese, which floats to the surface and escapes.

Calcareous slags effect elimination of Sulphur from crude Iron.

The lower the Carbon and the higher the temperature the more calcareous must the slag be to effect desulphurisation.

It is always more easy to remove the bulk than it is to eliminate the residue.

THE SULPHUR-BEARING MINERALS IN IRON-MAKING MATERIALS.

The compounds in which sulphur is found in iron-making materials are few in number, they are Iron Pyrites $Fe\ S_2$, Magnetic Pyrites FeS, Calcium Sulphate $Ca\ SO_4$, and Baruim Sulphate $BaSO_4$. Occasionally zinc, lead and copper sulphides are found. These, however, rarely exist in more than traces in the materials generally available in Europe.

METHODS OF REMOVING THE SULPHUR-BEARING MINERALS.

Hand Picking.—The removal of these minerals, when in sufficient quantity to justify removal, may be performed by hand picking, as is done in the case of some ores and coal, when there are segregated lumps of such dimensions as to be easily detected. In such case the material is run over screens or belts. The Pyrites in coal and in some iron ores, and Barium Sulphate in some of the ore in the South of Spain are removed in that way.

WASHING.—Washing is, however, the more usual method for removing Pyrites from coal, the Sulphur-bearing mineral, FeS_2 being so much heavier than the coal itself, the separation is easily effected.

CALCINATION.—Calcination when applied to ores free from lime is capable of removing the greater part of the Sulphur in the Pyrites, but if sufficient lime as carbonate is present the gaseous Sulphur Dioxide produced attacks the Carbonate, and in the presence of an excess of Oxygen the whole of the Sulphur is retained by the lime as Calcium Sulphate. The reactions are :—

$$2FeS_2 + O_9 + (CaCO_3)_4 = Fe_2O_3 + (CaSO_4)_4 + CO_2$$

As Sulphate of Lime is soluble in water, it has been the practice in one large Continental works to place the calcined ore in tanks and to wash out the Sulphate with water. I have no data as to what proportion of Sulphur is so removed, but there must be a material advantage in the use of such treatment, otherwise it would not be continued. It is certain that wherever it is adopted an enormous water supply would be a sine qua non. Experiments made in this country have proved that washing calcined ore containing lime, although removing sulphates, caused disintegration.

MAGNETIC SEPARATION.—Where the ores are magnetic and it is necessary to concentrate the iron-bearing minerals, magnetic separation effects a satisfactory separation of the Sulphide, but this is rendered less easy when the Sulphur exists, as it sometimes does, in the mineral magnetic pyrites.

RELATIVE HARMFULNESS OF SULPHUR-BEARING MINERALS IN IRON ORES.

Metallurgists are often asked whether the Sulphur in Iron ores as Calcium Sulphate is as harmful as if present as Iron Pyrites. Judging from purely hypothetical reasoning, if Iron Pyrites is associated with an excess of Lime in Iron ore and is distributed uniformly throughout the lumps of ore, and should the Silica be in very small proportion, the resultant will be Calcium Sulphide. Provided the Lime is sufficient to make a good slag under normal conditions of working this Sulphide will probably not give up its Sulphur to the Iron, unless Silica from coke ash comes in contact with the Sulphide, but the Calcium Sulphide will be absorbed by the Lime and carried away with the slag when it reaches the melting zone.

If, instead of Pyrites, Calcium Sulphate were present, other conditions being identical, the result would be the same.

It is unfortunate, however, that the conditions just given rarely obtain in practice, for Lime is not often present in sufficient quantity or the Silica low enough to admit of such easy disposal of the Sulphur.

The more usual relative proportions of the Lime to Silica in Iron ores is such that the Lime is not in quantity sufficient to combine with the Silica to form CaO SiO_2, and a considerable addition of Limestone is therefore required to flux the excess of Silica so as to make a satisfactory slag $(CaO)_3$ $(SiO_2)_2$. In such case the Sulphur from the Pyrites will be retained by the Iron and form FeS, until after sufficient carburisation it becomes fluid, and comes in contact with the Lime of the added Limestone, when more or less of the Sulphur will be removed from the Iron, according to the conditions existing at the time.

In the case of the Sulphur being present as Calcium Sulphate and distributed evenly throughout the lumps of Iron ore and in contact with excess of Silica and Carbon, the Silica having more powerful attraction for the Lime than the Sulphur, Calcium Silicate and Sulphide of Iron are the result,

$$CaSO_4 + SiO_2 + Fe + 3C - CaSiO_3 + FeS + 3CO.$$

In this hypothetical case it is assumed that the Calcium Sulphate and Silica are intimately associated. If, however, the Sulphate existed in separate segregated lumps the reactions given above would be modified, and probably only such part of the Sulphate as was attacked by the Silica in the solid ore would yield Sulphide of Iron, the bulk would be reduced to Calcium Sulphide, and would eventually be fluxed away by the limestone.

The same remarks apply to Barium Sulphate. Riley has, however, found that this compound sometimes forms a separate regulus with Iron and escapes both the Iron and slag. Possibly this only occurs when the quantity is excessive, for I have never met with it when ores containing only two or three per cent. have been smelted in the blast-furnace.

The following actual fact is very well recognised, that whether the Sulphur exists as Pyrites or as Sulphate of Lime in the Iron ore there is always a liability for that Sulphur to find its way into the Pig Iron.

Some little time ago, in order to ascertain the views of practical men in this country, I asked most of the manufacturers of hematite Pig Iron as to what their experience actually was. A chemist of one of the largest works stated that he had little doubt that a given quantity of Sulphur as Sulphate of Lime was much less harmful than the same amount of Sulphur as Pyrites. A director of another firm, however, stated that they believed Sulphur in any form was equally liable to pass into and be retained by the Iron.

Copper, Zinc, and Lead Sulphides when present readily yield their Sulphur to Iron when at a red heat; therefore, Sulphur in these minerals is as equally objectionable as that in Pyrites.

The Sulphur in the coal or coke exists partly as Sulphide, partly as Calcium Sulphate, and sometimes in a combination with Carbon and Hydrogen.

The Pyrites in the Coal when charged into a blast-furnace parts with a portion of its Sulphur when it is heated to a sufficiently high degree in its passage down the shaft of the blast-furnace, but this will be absorbed partially by the free Iron of the reduced Iron ore, partly by the Lime, and a minute portion will be carried out with the gases.

Messrs. F. Wurst and P. Wolff[19] say that a considerable quantity of the Sulphur must pass out of the coke in its descent through the furnace; that some undoubtedly does cannot be denied, but judging from my own trials it is small, and Mr. Wright, of the Newport Iron Works, informs me that coke taken from the twyers contains about the same quantity of Sulphur as the coke put in at the top of Cleveland furnaces.

Messrs. Wurst and Wolff[19] say that what Sulphur is volatilised under 800°C is mainly caught by the Iron ore, and what escapes from the coke at higher temperatures is caught by the Lime.

In following the coke downwards towards the twyers we must conclude that the Sulphur associated with that part of it which is attacked by the Carbon Dioxide is gasified, probably as Sulphur Dioxide.

It is certain, however, that most of what escapes from the coke will be caught by the Iron ore.

According to the authority of the gentlemen named above, there is a very minute proportion found in the gaseous form in blast-furnace gases.

Their results were as follow, viz. :—

	Balance Kilos.
Sulphur in ore 3.3901 Put in with Coke 6.899	10.2891
Carried out in dust	0.5238
Carried out in Gas	0.1489
In Pig Iron	0.3300
In Slag	9.2350
	10.2377

Until the coke actually passes into the oxidising region of the blast near the twyers, the Sulphur is mainly imprisoned in the body of the coke itself, and this can only become free at the most favourable time from the point of view of the manufacturer, for it is only liberated at the point of maximum temperature when there is an excess of Lime ready to take it up, and when the metal has become more or less highly carburised and silicised, a condition not favourable for its ready absorption of Sulphur.

It is for this reason that Sulphur in the coke is not so liable to pass into the metal as the Sulphur in the ore. In other words, it is less harmful to have Sulphur in coke than in the ore. All the Sulphur in the Limestone passes into the Slag unless the Slag is excessively siliceous.

REGULAR WORKING OF THE BLAST FURNACE.

If Blast Furnaces could always be worked with the regularity of a clock, so as to keep the melting zone or plane of fusion in an ideal position, and No. 1 Pig Iron be the invariable product, larger quantities of Sulphur in any form might be admissible in the Iron-bearing minerals than is considered allowable at present. It is impossible to discuss this question fully here, explaining why this is so. It is sufficient to know that it is a fact, and that therefore any and every means should be adopted in order to ascertain as soon as possible when irregularities arise, so as to be able to direct attention to the proper quarter and remove them.

Sometimes the blast will pass up one side of the furnace only, and the melting zone be extended high up to the boshes, whilst on the other side of the boshes the furnace may be relatively cold, a condition of things which is coincident with the production of very inferior sulphurous Pig Iron.

The chief method hitherto adopted for detecting whether the furnace was working regularly, or otherwise, was by trying-rods, which were lowered into the furnace through holes near the bell, for in this way it was possible to ascertain on which side of the furnace the materials were sinking most rapidly. It has occurred to me, as it must also have occurred to many other metallurgists, that if at the lower parts of the furnace means could be adopted for determining varying temperatures of the interior, indications might be obtained which would lead to the detection of such irregularities as I have referred to, and which are incapable of being detected by the trying-rods, for it is obvious that the side of the furnace along which the gases pass most freely will be relatively hotter than the other side through which little of the gas can penetrate. In modern furnaces these indications could be obtained by finding the temperature of the water flowing from the cooling plates, but perhaps a more perfect method would be to take the temperature by introducing pyrometers at different points partially through the brick lining.

This, of course, is only a suggestion for the consideration of practical Blast Furnace managers.

CONCLUSION.

In concluding this paper I must first of all acknowledge the valuable assistance given me by many ironmasters and their agents, to Mr. Westgarth for having cut and planed for me a great many specimens of Iron and Steel, to Mr. A. W. Richards, Mr. A. Cooper, Mr. C. H. Ridsdale, Mr. H. Goldsbrough, Mr. Foster, and Mr. A. Cochrane, for having furnished me, at considerable trouble and expense, with the specimens on which I have experimented, and to my own assistants, who have polished the specimens and made the analyses of the samples.

To anyone who can read between the lines of this paper, many gaps, many indications of our want of knowledge will be noticed, and it is hoped that this may inspire some of your members to endeavour, by observation and research, to throw more light on such an interesting subject as the relations of Iron-Sulphur and other metalloids after they have been melted and allowed to solidify.

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At the conclusion of Mr. Stead's remarks, as the evening was far advanced, and there was not time to do justice to so important a subject, it was decided that a special meeting should be devoted next session to the discussion.

THE PRESIDENT : We have had a most interesting lecture, and I think we shall look forward to Mr. Stead coming again to help us when the discussion is taken next session. Without further delay, I shall ask you to give him a very hearty vote of thanks.

This was carried unanimously by acclamation.

MR. J. E. STEAD : I thank you all very much, and I hope you have enjoyed it, and I hope you will not mind having to fill up the various gaps, and having, so to speak, to dot a lot of the " i's " for me. When I give a lecture I think it is absolutely time and trouble wasted unless some are induced to follow in my steps, and I hope, therefore, some of you will take this subject up in earnest, and will blossom out into original investigators.

THE ANNUAL MEETING.

The Annual Meeting was held at the Station Hotel, Dudley, on Saturday, 25th April, 1908.

The retiring President (Mr. R. Buchanan) presided during the first part of the meeting.

The minutes of the last meeting were read, approved, and signed.

Messrs. S. Y. Cook, H. E. Hunt, W. E. Hunt, Fred Platt, and Charles C. Walker were elected members of the Institute.

The Secretary read the Report of the Council for the Session, as follows :—

REPORT OF COUNCIL 1907-1908.

The Annual Excursion took place on the 19th June, 1907, when about 100 Members visited Rugby. On arrival the Members inspected the Works of Messrs. Willans and Robinson, being conducted over the various departments by Mr. Eaton-Shore and other Members of the Staff. Luncheon was served at the "George Hotel," and the President conveyed the thanks of the Members to Messrs. Willans and Robinson's Staff for their courtesy.

After luncheon the Members visited the Works of the British Thomson Houston Co., Ld., and were conducted over the whole of that establishment. On leaving, a vote of thanks was passed to the British Thomson Houston Co. for allowing the Members to visit the Works. Tea was served at Rugby Station, and the party returned home soon after 6 p.m.

Six Ordinary Meetings have been held during the year :—

28th Sep., 1907.	Address by President.
19th Oct., 1907.	Paper by Mr. George Hailstone on "The "Action of the Metalloids on, and the "Microstructure of Foundry Irons."
23rd Nov., 1907.	Paper by Mr. J. Ernst Fletcher on "The "Influence of Gases on the Structure of "Iron and Steel."
21st Dec., 1907.	Paper by Mr. Alexander Jude on "The "Variability of Steel."

18th Jan., 1908.	Paper by Mr. Josiah Butler on "The "Manufacture of Concrete Bricks from "Blast Furnace and other Slag."
21st Mar., 1908.	Lecture by Mr. J. E. Stead, F.R.S., on "Sulphur and Iron."

MEMBERSHIP.—There has not been any change in the number of Honorary Members during the year. Fourteen Ordinary Members have joined; two have died, viz., Messrs. T. H. Smith and G. Williams; seven have resigned; two have left; and one has been struck off. The present number of Members is as follows :—

Honorary	47
Ordinary	243
Total	290
Total in April, 1907	288
Increase	2

FINANCE.—From the accounts to be presented it will be seen hat the balance in hand on the 31st December last was £240 2s. d.; accounts unpaid at that date, £72 13s. 6d.; net balance, £167 8s. 10d.

For the Council,

(Signed)

R. BUCHANAN, President.

WILLIAM H. CARDER, Secretary.

In the absence of the Treasurer the audited balance sheet was ead by Mr. Harold Piper.

On the motion of the PRESIDENT, seconded by Mr. JNO. KEELING, the report and balance sheet were adopted, and ordered o be printed in the proceedings for the Session.

PROFESSOR TURNER enquired what sum the Council had invested, and moved "That the Council be authorised to increase he amount of the Institute's investments, if they consider it advisable."

Mr. WALTER JONES seconded, and it was carried.

The PRESIDENT proposed the name of Mr. W. J. Foster as President of the Institute for the coming year, remarking that the omination of the Council would meet with the hearty approval of the members. Mr. Foster was widely known to the members as an able blast furnace manager. He had contributed clever papers alike to the meetings of the Institute and to the meetings of the Iron and Steel Institute in London. As President Mr. Foster would, he believed, forward the interests of the Institute in the same able manner he brought to bear upon all he took in hand.

The proposition was seconded by Mr. Wm. Somers, supported by Mr. Walter Jones, and carried unanimously.

The new President, having taken the chair, thanked the Institute for the honour. He was conscious of his shortcomings, but he would promote the welfare of the Institute to the utmost of his ability while in office. He moved a vote of thanks to the retiring President, observing that during the past year the chair had been filled with exceptional dignity. The Institute was especially indebted to Mr. Buchanan for having procured some very valuable papers.

Professor Turner seconded. Every member present, he said, would have liked the privilege which had fallen to himself. The Institute was much indebted to the retiring President for all he had done in advancing the cause of scientific ironfounding during twenty years past, and they greatly appreciated his work.

The vote was accorded with enthusiasm.

The President submitted the name of Mr. Walter Macfarlane for Vice-President. Mr. Macfarlane was an expert in metallurgy.

Mr. Buchanan seconded the more readily since, after himself, Mr. Macfarlane would be the second Scotchman to fill the chair of the Institute.

The motion was carried, and Mr. Macfarlane briefly acknowledged the vote.

Mr. James Piper was re-elected Treasurer, and Mr. W. H. Carder was re-elected Secretary.

The following were selected to fill vacancies on the Council, viz., Robert Buchanan, Isaac E. Lester, and J. Ernst Fletcher, and it was resolved that the Council for the ensuing year consist of Messrs. John Bate, Wm. Brooks, Robert Buchanan, Alfred Cookson, Richard Edwards, C. E. Edwards, A. E. A. Edwards, David Evans, J. Ernst Fletcher, Jno. W. Hall, W. H. B. Hatton, G. H. Head, Walter Jones, Isaac E. Lester, R. Lythgoe, Frank East Nurse, W. B. Rubery, Harry Silvester, Wm. Somers, Leyshon D. Thomas, and Thomas Turner.

On the suggestion of a member, it was understood that in future the attendances of members of the Council should be registered.

THE ANNUAL EXCURSION.

It was resolved that the annual excursion of the Institute should be to the works of Messrs. Thos. Firth and Sons, Sheffield.

THE ANNUAL DINNER.

The Annual Dinner took place at the Station Hotel, Dudley, on April 25th, 1908, the President, Mr. W. J. Foster, presiding.

Succeeding the toast of "The King,"

The **Mayor of Dudley** (Mr. F. W. Cook) proposed "The Iron, Steel, and Coal Trades." His Worship said that no one more than he recognised the good work which the Institute was doing. The industries to whose prosperity he had to ask them to drink were great, not only in this country, but abroad, and while it may not have been to the business advantage of South Staffordshire, it would always be to its honour that the district had in the past contributed so largely in the founding of the iron and steel trades of the greatest of modern producers of these metals, he referred to America. The native genius of South Staffordshire in the matter of iron and steel making had been aided and fostered by the past operations of the Institute, and the services which the Institute had rendered to the iron and steel trades of this and other countries, would, he firmly believed, be brilliantly added to in the future. As had often been remarked, there was no finality in iron manufacture, and in the fresh developments and discoveries which were ahead that district and that Institute would, he was confident, bear an important part. The uses to which iron and steel were being put in the services of the world were constantly extending. New and large employments were being found for the metals, and gulfs between nations were now being bridged by their aid. Majestic as was the past history of the trades he had to propose, their future would be yet more magnificent. One of the most gratifying features of the iron and steel manufacture of to-day was the success which was attending efforts at economy, particularly in the direction of the utilisation of waste products. He hoped that the time was not far off when methods would be devised for utilising the wealth at present lying dormant and neglected in the colliery spoil banks. It was in inventions in this and allied directions that Institutes like theirs could prove the value of their existence. A revolution was badly needed in the manner of our coal consumption. This was no new topic, but the outcry which was periodically made respecting the alleged exhaustion of British coal deposits gave point to the efforts at reform. There was no one who could defend the existing wasteful methods of fuel consumption. His Worship expressed himself as one of those who cherished the belief that by and bye a reform would be introduced as important and far-reaching in its effects as any past discoveries connected with iron and steel. Referring the the high price of coal, his Worship appealed to the coalmasters of South Staffordshire to reduce the price wherever possible that the district's industries might have the better opportunity of competing with other parts of the Kingdom. There were circumstances—perhaps they were very operative to-day—in which the price of coal was bound to be high. But it was a serious question whether the situation did not constitute a danger to the prosperity of South Staffordshire. The present was an age of combines and rings for advancing the interests of various industries associated with the iron and steel trades. They had their benefits as well as their faults. From British Consular reports he gathered that in many of the export markets German commercial travellers were much more numerous than English travellers. This should not continue. Whatever the issue of the existing Tariff Reform agitation, it would never do to leave our export markets at the mercy of competitors' travellers. He would suggest that great benefit might accrue to, say, the local chain, cable, and anchor trades from a combination amongst the makers to send out special representatives to various parts of the world.

Mr. George Hatton, in the course of his response, said that a year ago the commercial horizon was cloudless. In periods of sudden and severe depression, such as trade had now to encounter, the careful observer was filled with admiration that a comparatively small iron and steel district like South Staffordshire could sustain so brave a fight. The secret was largely in the great variety of industries centreing round South Staffordshire, and to whose prosperity the iron and steel trades proper ministered. Scotland and the North of England, although situated geographically much more favourably than the Midlands for export trade, were feeling the depression much more severely than this district, the reason being their reliance upon the one great industry of shipbuilding for the bulk of their orders. Added to this, at the moment, were severe labour troubles in the shipyards, which it was to be hoped would early pass away. The reversal which since their last annual dinner had been seen in the trade conditions was world-wide. The productive iron and steel capacity of America had been reduced at the very least fifty per cent., and in Germany the reduction had been perhaps as much. There were, however, some redeeming features in the current trade depression that had been entirely absent on previous occasions. To these he would like to direct the Institute's very careful attention. The American iron and steelmasters, especially, were exhibiting quite a different spirit to what had been customary. Instead, as aforetime when things were bad, keeping their production at the maximum, and dumping their surplus make abroad, no matter what its price, they were now, as he had shown, enormously curtailing output and maintaining their home prices. This important change in policy was as wise as it was welcome. He ventured to prophecy that the issue would be altogether beneficial to the great sister industry across the Atlantic. Under the changed conditions to which he had referred the American iron and steel trades would recover from the present severe period of depression very much more quickly than had full production and dumping again been resorted to.

Mr. H. PILKINGTON, replying to the toast, said that in 1907 Mr. Buchanan, the then President, described him as a pessimist owing to some remarks he made. He pleaded guilty to having assumed the rôle of a prophet; he warned them that the high prosperity then characterising the iron and steel trades would not last. Now the slump had come. What Mr. George Hatton had said was perfectly true—indeed, he believed that production in America had been curtailed more than the fifty per cent. spoken of by Mr. Hatton. The changed policy of American ironmasters, and the abandonment of their dumping tactics, was a very fortunate thing for this country's iron and steel producers. In the course of the recent prosperity large outlay had been incurred at many British works in improvements in plant and equipment. Such action was entirely wise. And it so happened, fortunately for those responsible for management, that it was in times of good trade that, as a rule, Boards of Directors were the most easily persuaded to sanction expenditure upon works improvements. He saw a great change coming over the methods of conducting business in many industries of the country at the present time, and this change he regarded as very urgent. It was one which gave him new hopes for success in British commercial and manufacturing matters. He referred to the efforts which were witnessed in many trades just now of drawing closer together, in combination or agreement or association, to elminate internal competition. He ventured to forecast that that policy was going to become International. Already in some branches of the rolled steel trade, in the iron and steel tube trade, and in certain other industries, these International understandings or arrangements had commenced, and he foresaw that this tendency to form mutual associations in different countries would steadily widen and extend. The issues of such a policy would, he could not help thinking from the experience which had already been gained, be beneficial to each of the manufacturing countries taking part in it. "Spheres of influence," as they were at present termed, would be probably mutually mapped out, regulating the several countries in which the once competing signatories should be allowed to sell their manufactured products, and output would be regulated, so that International competition, if not ended, would be largely controlled. Prices to the consumers would by these means be kept up, or, at any rate, kept at a paying level to the manufacturer, and so disaster to trade through enlarged International output be prevented. There was a possibility that these commercial manufacturing understandings between nations might even supersede the necessity for a national fiscal change in this country. The wisdom of some sort of International rapprochements in iron and steel manufacture was seen when the rapid increase which still continued in output was recalled. Last year, out of an assumed figure of sixty million tons for the world's pig iron production, the United States made 25,786,000 tons, Germany 13,045,000 tons, and Great Britain 10,000,000 tons. The English make was a small decrease on 1906, and the decrease still continued. The British export returns for the first quarter of this year showed a decrease in the iron and steel and allied exports of 1,100,000 tons. For the same three months our imports of iron and steel increased 211,000 tons. Mr. George Hatton had directed attention to the changed policy which the American iron and steel masters were following at the present time with respect to "dumping" surplus make abroad. The change was a most welcome one. For himself, however, he should not be surprised to witness at any moment a resumption of Continental "dumping." The Continental position of large output simultaneously with a curtailed home consumption would, he thought, almost compel a revival of their "dumping," though it was doubtless correct that for the present the make in Germany had been reduced almost as severely as across the Atlantic. In conclusion, he said he was opposed to the principle of declining to attempt new departures in methods of conducting trade and manufactures. The iron and steel trades must adapt themselves to the circumstances of the times. The one paramount duty of British ironmasters was to see to it that they got their fair share of the trade of the world. If it was necessary to adopt the methods of our adversaries to do this those methods should be adopted, but our rightful share of the world's trade must be ours.

ALDERMAN JOHN HUGHES said that he agreed with the Mayor that the trades of South Staffordshire were badly asking for cheap coal. But, he was afraid, they would never get it. They would have to look forward to a continuance of present high prices. Indeed, should the Government Miners Eight Hours Bill become law, coal would become still dearer. Reference had been made to the exports of coal from this country last year, which totalled forty-five million tons. Well, this continued export had to be admitted, and it was one of the circumstances which iron and steel masters had to consider in attempting to arrive at forecasts of what the future course of the coal market in respect of prices might probably be. Notwithstanding dear coal, however, there was a prosperous future before South Staffordshire. The ability of her works proprietors and of her works managers would surmount what might at first appear to be a very serious obstacle. What South Staffordshire had done in the past the district would prove itself still capable of accomplishing. The fascinating chapter of Black Country invention and resource was not yet closed. Happily, there would still be available to the district's industries an abundant supply of coal, though it might be dear. As they all knew, after ten years of patient labour, coupled with a heavy capital expenditure, and the pumping of millions of tons of water, the Earl of Dudley had succeeded in getting the shafts down at the new sinkings at Baggeridge, and the colliery was magnificently equipped. Earl Dudley's colliery engineers hoped that they would be drawing coal from the Baggeridge sinkings some time in 1909. By and bye, if his lordship could get the colliers and their agents in the right mind, his lordship hoped to be drawing some 3,000 tons a day. In addition to the Baggeridge colliery, a twin plant was also being put down at the Sandwell Park Colliery, and in the course of the next few months it would probably be engaged in raising coal. It would be seen, therefore, that there was yet any amount of coal at command, and the Staffordshire iron trade would be saved the expense of having to bring fuel from other districts to the furnaces. He had spoken of dear coal, and he had expressed his belief that even with dear coal South Staffordshire ironmasters would still hold their own. He must not, however, be regarded as blind to the danger of the price question in relation to the cost of fuel getting out of hand. Cheap fuel was desirable for manufacturing interests if it could be provided, or at least a moderately priced fuel. Continental manufacture in iron and steel and the engineering industries had to be competed against, and would be a factor for many years to come. He therefore could not but express the hope that the colliers' leaders and Imperial legislation together would not drive prices to the extreme. Capital would be shy of investment—and what could be done without capital?—if matters were pushed to such a point that a fair return could not be obtained.

The toast of "The Institute" was submitted by ALDERMAN G. H. DUNN. He would, he said, have liked to have been provided with some figures giving the progress of the Institute over the past forty years. They all recognised that the course of their body had been one continuous progress. Long might it still go on. A great deal had been said about the coal question. He desired to join himself with the remarks of Alderman John

Hughes that South Staffordshire was about as likely to have cheap coal again as it was to have the moon. If the future prosperity of South Staffordshire was bound up with cheap coal, then good-bye to that prosperity. Neither cheap fuel nor low wages in the coal trade were again likely to occur. Neither did he, personally, wish for them. Low wages were neither good for masters nor men. That was a proposition he was quite prepared to substantiate, if called upon. He was an advocate of good wages, and plenty of work for those wages. He was sure that it was to a master's interests to pay a good workman good wages; and bad workmen, discontented workmen, only encouraged others to be dishonest and discontented. Mr. Pilkington had twitted the coalowners with putting up prices and making immense fortunes. Well, he had known a good many coal masters who had had to retire without making even big fortunes; indeed, he could remember a good many failures among colliery owners. He did not think Mr. Pilkington would be very successful in establishing his case. Though in the future fuel might be high, he saw no need why on that account iron masters should be despondent. He had become a good deal hardened when people talked to him about trade "depression." To the end of time trade prosperity would ebb and flow. The *raison d'être* of Institutes like theirs would be gone to-morrow were there not a continuous need for new thought and strenuous endeavour in the conduct of business. He trusted that the Institute would never take a desponding, or, still more, a despairing view of the prospects of their industry, but, when brought face to face with difficult times of trade, would turn its attention with increased and unflinching determination, by scientific attainment and productive insight, to beat down all hindrances.

The President (Mr. W. J. Foster) responded. The Institute had been in existence since 1866, and had rendered good service to the iron and steel trades of the district. He was proud to follow his predecessors in the Presidential chair, the more so since the communications which were to be found in the volumes of their "proceedings" would rank with some of the best work accomplished by any of the sister Institutes. The principal object for which the Institute was founded was to assist its members in the solution of the numerous scientific problems which were presented to iron and steel producers. The fundamental principles upon which those problems rested might be briefly described as matter, heat and energy. In no branch of iron and steel manufactures was a thorough knowledge of the operations, in all their varied ramifications and changes, of these three principles more essential than in the sphere in which he himself laboured, namely, blast furnace practice. As he had previously pointed out, it was impossible to arrive at an exact definition without considering the whole, and he would suggest that once the student had made himself familiar with the numerous changes that took place in the blast furnace, and the many varied phases that the contents of a blast furnace assumed, he would have no difficulty in solving most of the problems confronting him in any other furnace in existence. It was quite evident that the time was fast approaching when they would have to express power in £ s. d. The second place in the world of iron and steel producers was the least that Great Britain should seek once again to possess. With that object in view he hoped that both the district and the Institute, and not only that district and that Institute, but every iron and steel manufacturing centre of the Kingdom, and all scientific bodies having for their object the advancement of the interests of metallurgy in this country, would press forward. He suggested that the interests of the iron and steel industry might be advantaged by receiving in various ways more serious attention at the hands of the legislature. There was too much reason to fear that at present these great industries were being neglected by Parliament, and were suffering from that neglect. Such treatment was especially surprising in view of the necessity of these trades to the safety and well-being of the nation. They could not conceal from themselves the fact that the power which the German Empire, for example, was rapidly assuming in the Councils of the world was the direct result of the possession of a magnificent iron and steel industry. And what was true of Germany applied with equal force to America and France and some other nations. The giant strides which Germany and America had made as iron and steel producers were peculiarly suggestive. Everything went to show the importance of possessing abundant and cheap raw materials. In this respect their own district was fairly fortunate. The railway and canal companies, however, might help Staffordshire and the Midlands much more than they were doing. Increased facilities for the transport of raw materials was one of the greatest needs of these industries. If a tangible and lasting improvement in these conditions could be obtained he believed he would not be saying too much when he said that the trade of Staffordshire was in its infancy.

"Kindred Associations" was proposed by Mr. Walter Jones, coupling with it the name of Mr. Isaac Lester, President of the Birmingham Metallurgical Society, who responded.

THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

BALANCE SHEET,

Dr. *FOR THE YEAR ENDING* 31*st* *DECEMBER*, 1907. **Cr.**

Dr.	£ s. d.
To Balance brought forward	156 . 19 . 4
,, Subscriptions	168 . 8 . 6
,, Books and Papers sold	1 . 8 . 6
,, Interest on Invested Funds	3 . 10 . 1
	£330 . 6 . 5

Cr.		£ s. d.
By Expenses at Annual Meeting		9 . 1 . 10
,, Printing and Stationery		73 . 13 . 9
,, Shorthand Notes		17 . 17 . 11
,, Postages and Telegrams		18 . 1 . 8
,, Carriage and Sundry Expenses		3 . 6 . 5
,, Rent		8 . 0 . 0
,, Secretary's Honorarium		20 . 0 . 0
		150 . 1 . 7
,, Printing and Binding Proceedings supplied to the Cleveland Institute of Engineers		12 . 16 . 0
		162 . 17 . 7
Invested at 2½ per cent.	£122 . 11 . 2	
In Treasurer's hands	117 . 11 . 2	
	240 . 2 . 4	
Less Accounts Outstanding	72 . 13 . 6	
		167 . 8 . 10
		£330 . 6 . 5

Examined with Vouchers and found correct this 14*th day of April*, 1908.

WALTER W. PAGETT, } AUDITORS.

RULES.

REGISTERED NO. 943, WORC.

1.—The Society shall be designated "The Staffordshire Iron and Steel Institute." Its registered office is in England, and is at the Institute, Wolverhampton Street, Dudley, in the County of Worcester. In the event of any change in the situation of the registered office, notice of such change shall be sent within 14 days thereafter to the Registrar, in the form prescribed by the Treasury Regulations in that behalf.

2.—This Society is subject to the provisions of the Friendly Societies' Act, 1875, except so much thereof as relates to dividing societies (section 11, sub-section 4); the certification of annuities (section 11, sub-section 5); appeals from a refusal to register a society or any amendment of the rules thereof (section 11, sub-sections 8 and 9, and section 13, sub-section 3); or from cancelling or suspension of registry (section 12, sub-section 4 and part of sub-section 5); quinquennial returns and valuations (section 14, sub-section 1, *e f*); certificates of death (section 14, sub-section 2, and section 15, sub-section 9), exemption from stamp duty (section 15, sub-section 2); nomination and distribution (section 15, sub-sections 3, 4, and 5); priority on death, bankruptcy, &c., of officers (section 15, sub-section 7), copyholds (section 16, sub-section 6); loans to members (section 18); the accumulation of surplus of contributions for members' use (section 19); so much of section 22 as relates to the reference of a dispute to the chief or any other Registrar; the amalgamation, transfer of engagements, and dissolution of Friendly Societies (section 24, proviso to sub-section 8, and section 25, sub-section 1, *c*, and sub-section 7); militiamen and volunteers (section 26); the limitation of benefits (section 27); payments on the death of children (section 28); societies receiving contributions by collections (section 30); cattle insurance and certain other societies (section 31); and the four last heads of Schedule II.

3.—The objects of the Institute are:—To promote the intellectual welfare of its members by periodical meetings for reading and discussing scientific papers on subjects connected with the Iron and Steel Trades, and such other matters as may be considered within the scope of the special authority of 3rd July, 1878 ("The Promotion of Literature, Science, and Fine Arts.") The expenses incurred in carrying out the above objects shall be provided by the subscriptions of Life and Honorary Members, the entrance fees and periodical contributions of Ordinary Members, and from interest upon any accumulated capital.

CONSTITUTION.

4.—The Institute shall consist of Life, Honorary, and Ordinary Members, who shall be more than twenty-one years of age, and shall be either owners, managers, assistant managers, and other officials of iron and steel works, mechanical or mining engineers, analytical chemists, draughtsmen, or persons of scientific attainments in metallurgy, or specially connected with the application of iron and steel.

HONORARY MEMBERS.

5.—Any person connected with the Iron and Steel Trades may, on the invitation of the Secretary or any other officer, become an Honorary Member of the Institute, on payment of One Guinea yearly to its funds, such payment to entitle him to receive invitations to all meetings of the Institute, and copies of all its publications. Any Honorary Member may become an Hon. Life Member by the payment of Ten Guineas.

ELECTION OF ORDINARY MEMBERS.

6.—Any person desirous of becoming an Ordinary Member of the Institute must be proposed according to Form A in the Appendix, and the form sent to the Secretary and by him laid before the next meeting of the Council. The name, occupation, and address of each candidate whose nomination has been approved by the Council, together with the names of his proposers, shall be printed in or sent with the circular convening the next Ordinary Meeting.

7.—The election shall take place at an ordinary meeting; a two-thirds majority of the members present being necessary for election.

8.—When the proposed candidate is elected, the Secretary shall give him notice thereof, according to Form B; but his name shall not be added to the list of members of the Institute until he shall have paid his entrance fee and first annual subscription, and signed Form C in the Appendix.

9.—In the case of non-election, no mention thereof shall be made in the minutes, nor any notice be given to the unsuccessful candidate.

SUBSCRIPTIONS.

10.—The Subscription for an Honorary Member shall be One Guinea per annum, and for an Honorary Life Member Ten *Guineas,* as provided by Rule 5. Each Ordinary Member shall pay an entrance fee of Two Shillings and Sixpence and an annual subscription of Ten Shillings and Sixpence; or he may become an Ordinary Life Member by the payment of Five Guineas. All annual subscriptions shall be payable in advance, and shall be due on the First day of January in each year.

11.—Any member whose subscriptions shall be two years in arrear shall be thereby disqualified, and the Council, after having given due notice, in the Form D in the Appendix, shall remove his name from the list of members, unless satisfactory reasons are given to the contrary.

OFFICERS.

12.—The officers of the Institute shall consist of a President, a Vice-president, Twenty-one Members of the Council, Three Trustees, a Treasurer, and a Secretary, who shall be elected at the annual meeting by show of hands. The President, Vice-President, Treasurer, and Secretary, shall be *ex-officio* members of the Committee of Management, herein termed Council. Officers may be removed by a special general meeting.

13.—In addition to the *ex-officio* members, the Council shall consist of Twenty-one members, all of whom shall retire annually, but shall be eligible for re-election, with the exception of those who have not attended any of the Council meetings called during the year for which they have been elected.

14.—The Council shall meet as often as the business of the Institute requires; seven to form a quorum. Such meetings to be called by the Secretary, of which seven clear days' notice shall be given.

15.—The Council shall appoint from its own body two Committees, one to be called the Finance Committee, which shall advise the Council on matters relating to the receipts and expenditure of the Institute; and the other to be called the Publication Committee, which shall arrange for suitable papers to be read at the meetings of the Institute, and shall undertake the revision of all printed transactions. The Council shall provide the Secretary with a sufficient number of copies of the Rules to enable him to deliver to any person on demand a copy of such Rules, on payment of a sum not exceeding One Shilling; and it shall be the duty of the Secretary to deliver such copies accordingly.

DUTIES OF OFFICERS.

16.—The President shall be chairman at all meetings at which he shall be present, and in his absence the Vice-president. In the absence of the Vice-president, the members shall elect a chairman for that meeting.

17.—The Treasurer shall hold in trust the uninvested funds of the Institute, which shall be deposited at a bank approved by the Council; he shall receive from the Secretary all amounts paid by way of subscription, contribution, or payment; and shall pay all accounts that are properly certified as correct by the President and Secretary. He shall keep proper books of account, and shall submit them once a year, or oftener if required by the Council, to the Auditors appointed, and shall supply the Secretary with a duplicate copy of his balance sheet.

18.—The Secretary shall attend all meetings, carry on the general business and correspondence of the Institute, arrange meetings for the reading of papers and for other purposes, and keep minutes of all proceedings, which shall be authenticated by the signature of the Chairman. He shall collect all subscriptions and pay the same to the Treasurer, and shall prepare and send the Returns required by the Friendly Societies Acts and the Treasury Regulations to be sent to the Registrar. He shall be paid an honorarium on March 25th in each year, in addition to any sums he may expend on behalf of the Institute for postages, stationery, printing, or travelling expenses.

19.—The Trustees, each of whom must be a householder, and in whose names the properties and surplus funds of the Institute shall be invested, shall continue in office during the pleasure of the Institute, and in the event of any of them dying, resigning, or being removed from office, another or others shall be elected at the next general meeting of the Institute. A copy of every resolution appointing a Trustee shall be sent to the Registrar within fourteen days after the date of the meeting at which such resolution was passed, in the form prescribed by the Treasury Regulations in that behalf.

MEETINGS.

20.—The Annual Meeting shall be held in April in each year.

21.—General Meetings shall be held as often as business requires. The place of such meetings to be decided at the previous annual meeting.

22.—The President or the Council, in case he or they at any time think it necessary, or the President, on the requisition of six members may convene a Special General Meeting of the Institute, for the consideration of any subject requiring the immediate attention of members. The business of such meeting shall be confined to the special subject named in the notice convening the same.

23.—All members shall have at least six clear days' notice of, and be entitled to attend, each metting of the Institute, and to receive copies of the Institute's publications gratuitously.

24.—No alterations of the Rules shall be made except at a general meeting, and four weeks' notice in writing must be given to the Secretary of any proposed alterations. No amendment of Rules is valid until registered.

AUDITORS.

25.—The accounts, together with a general statement of the same and all necessary vouchers, up to the 31st December then last, shall be submitted once in every year to two auditors, appointed by the members at the general meeting preceding each annual meeting, who shall lay before every such meeting a balance sheet (which either may or may not be identical with the annual return, but must not be in contradiction to the same), showing the receipts and expenditure, funds and effects of the Institute, together with a statement of the affairs of the Institute since the last meeting, and of their then condition. Such auditors shall have access to all the books and accounts of the Institute, and shall examine every balance sheet and annual return of the receipts and expenditure, funds and effects of the Institute, and shall verify the same with the accounts and vouchers relating thereto, and shall either sign the same as found by them to be correct, duly vouched, and in accordance with law; or shall specially report to the meeting of the Society before which the same is laid in what respects they find it incorrect, unvouched, or not in accordance with law; and the balance sheet or report shall be published in the *Proceedings* of the Institute.

COMMUNICATIONS OF MEMBERS AND OTHERS.

26.—All communications shall be submitted to the Council, and after their approval, shall be read at the general meetings. All communications shall be the property of the Institute, and shall be published only in the *Proceedings* of the Institute, or by the authority of the Council.

PROPERTY OF THE INSTITUTE.

27.—All books, communications, drawings, and the like shall be accessible to all the members. The Council shall have power to deposit the same in such place or places as may be considered most convenient for the members.

INVESTMENT OF FUNDS.

28.—As much of the funds of the Institute as may not be wanted for immediate use, or to meet the usual accruing liabilities, shall, with the consent of the Council, or a majority of the members of the Institute, present at a general meeting, be invested by the Trustees in such of the following ways as the Council or General Meeting shall direct, namely, in the Post Office Savings Bank, in the Public Funds, or with the Commissioners for the reduction of the National Debt, upon Government or real securities in Great Britain, or upon the security of any County, Borough, or other rates authorised to be levied or mortgaged by Act of Parliament.

ANNUAL AND OTHER RETURNS.

29.—It shall be the duty of the Committee of Management to keep a copy of the last annual balance sheet of the Society for the time being, together with the Report of the Auditors, if any, always hung up in a conspicuous place at the registered office of the Society.—Friendly Societies Act, 1875, s. 14 (1 *i*.).

30.—The books and accounts of the Society shall be open to the inspection of any member or person having an interest in the funds of the Society at all reasonable times, at the registered office of the Society or at any place where the same are kept, and it shall be the duty of the Secretary to produce them for inspection accordingly.

31.—Every year before the 1st June, the Committee of Management shall cause the Secretary to send to the Registrar the annual return, in the form prescribed by the Chief Registrar of Friendly Societies, required by the Friendly Societies Act, 1875, of the receipts and expenditure, funds and effects of the Society, and of the number of members of the same, up to the 31st December then last inclusively, as audited and laid before a general meeting, showing separately the expenditure in respect of the several objects of the Society, together with a copy of the Auditors' Report, if any.

32.—Such return shall state whether the audit has been conducted by a public auditor appointed under the Friendly Societies Act, 1875, and by whom, and if such audit has been conducted by any persons other than a public auditor, shall state the name, address, and calling or profession of each of such persons, and the manner in which, and the authority under which, they were respectively appointed.—Friendly Societies Act, 1875, s. 14 (1 *d.*)

33.—It shall be the duty of the Committee of Management to provide the Secretary with a sufficient number of copies of the annual return or of some balance sheet, or other document duly audited, containing the same particulars as in the annual return as to the receipts and expenditure, funds and effects of the Society, for supplying gratuitously every member or person interested in the funds of the Society, on his application, with a copy of the last annual return of the Society, or of such balance sheet or other document as aforesaid, for the time being, and it shall be the duty of the Secretary to supply such gratuitous copies on application accordingly.—Friendly Societies Act, 1875, s. 14 (1 *h*).

DISSOLUTION.

34.—The Society may at any time be dissolved by the consent of three-fourths of the members, including honorary members, if any, testified by their signatures to some instrument of dissolution in the form provided by the Treasury Regulations in that behalf.

DISPUTES.

35.—If any dispute shall arise between a member, or person claiming through a member, or under the Rules of the Society, and the Society or any officer thereof, it shall be referred to justices pursuant to the Friendly Societies Act, 1875, s. 22 (*c.*)

APPENDIX.

FORM A.

THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

Mr.

of

being of full age and desirous of becoming a member of The Staffordshire Iron and Steel Institute, we, the undersigned, from our personal knowledge, do hereby recommend him for election.

His qualifications are

Witness our hands this day of 190

} Names of two members.

If elected a member of The Staffordshire Iron and Steel Institute, I, the undersigned, do hereby engage to ratify my election by signing the Form of Agreement (C) and paying the Entrance Fee and Annual Subscription in conformity with the Rules.

Witness my hand this day of 190

FORM B.

THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

To

Sir,

I beg to inform you that on the
you were elected a member of The Staffordshire Iron and Steel Institute, but in conformity with the Rules, your election cannot be confirmed until the accompanying form be returned with your signature, together with your Entrance Fee and first Annual Subscription. (Amount, £ s. d.)

If this amount be not received in one month from this date, your election will become void.

I am, Sir,
Yours truly,
Secretary.

day of 19

FORM C.

THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

I, the undersigned, being elected a member of the Staffordshire Iron and Steel Institute, do hereby agree that I will be governed by the rules of the Institute, and that I will advance its interests as far as may be in my power. Provided that if I signify in writing to the Secretary that I am desirous of withdrawing my name therefrom, I shall (after paying all arrears which may be due by me at that period) be free from this obligation.

Witness my hand this day 19

Member's Signature.

FORM D.

THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

Dear Sir,

I am directed by the Council to inform you that your subscription to the Institute, amounting to is still in arrear, and that if the same be not paid to me on or before the day of your name will be removed from the lists of the Institute.

Yours faithfully,

Secretary.

OFFICERS FOR SESSION 1908-1909.

President:

WILLIAM J. FOSTER.

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" Colliery Guardian."
" Engineering."
" Iron and Coal Trades Review."
" Iron and Steel Trades Journal."
" Science and Art of Mining."
" Page's Weekly."
" Stahl und Eisen."

They are also presented to the Library of the Patent Office, London, and the Library of the University, Birmingham.

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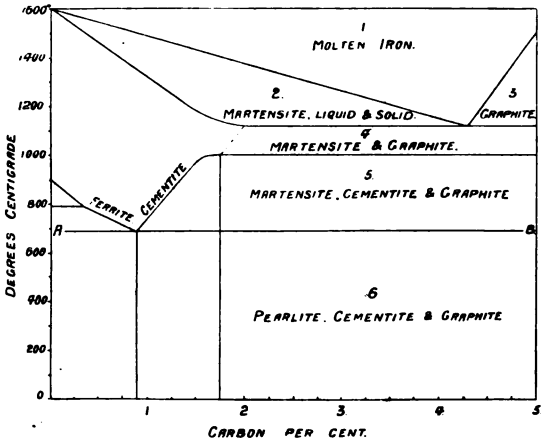

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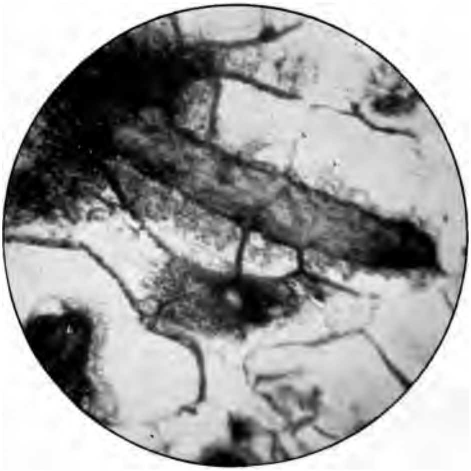

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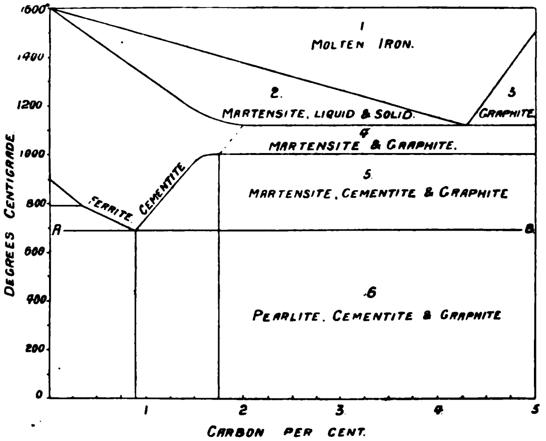

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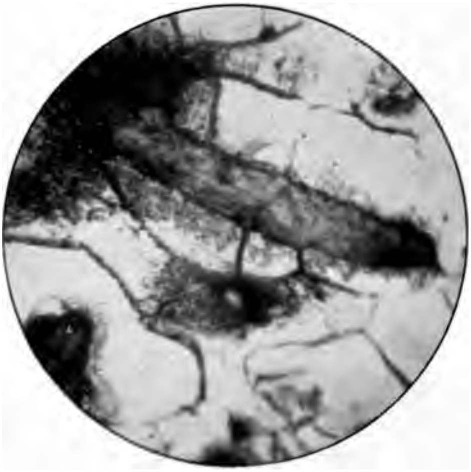

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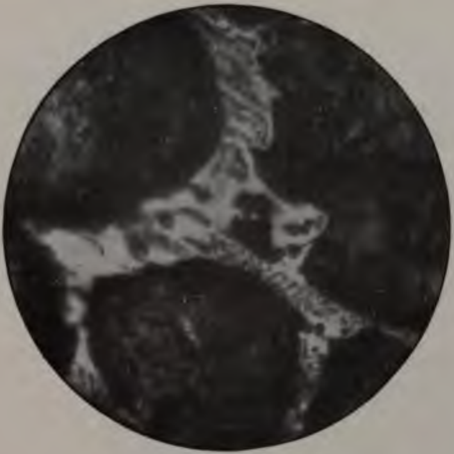

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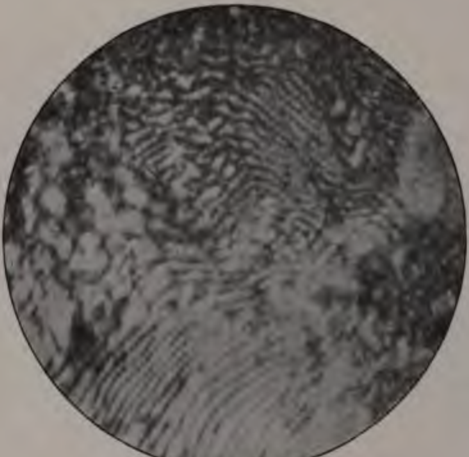

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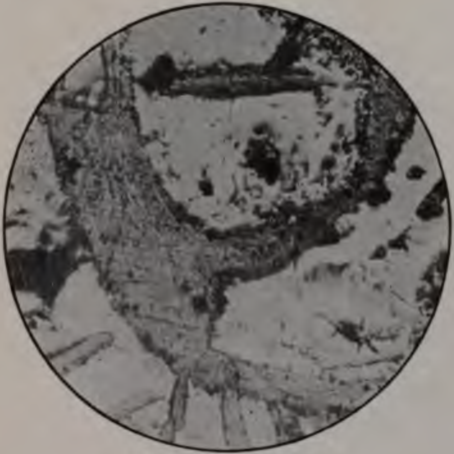

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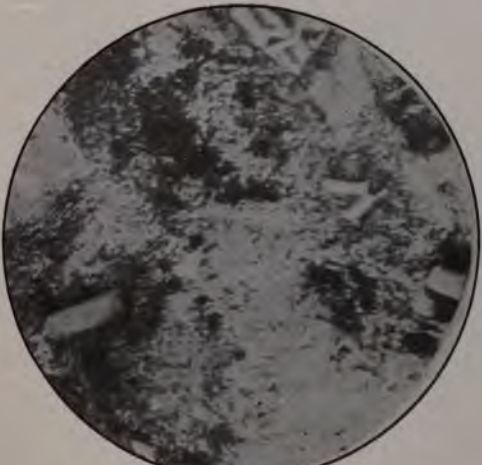

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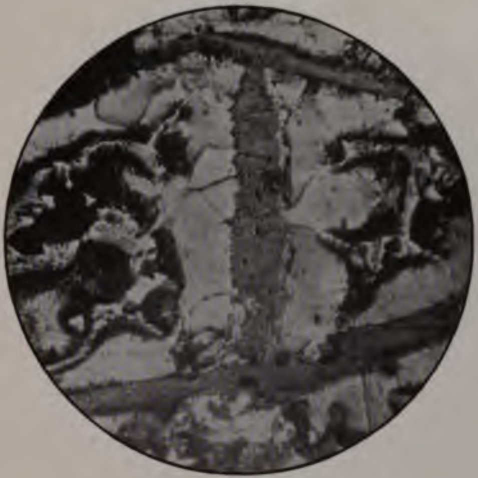

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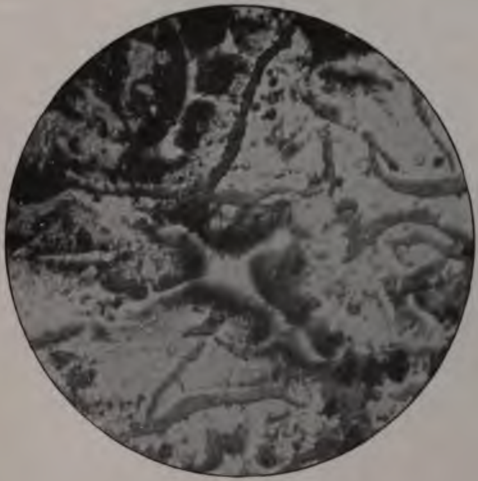

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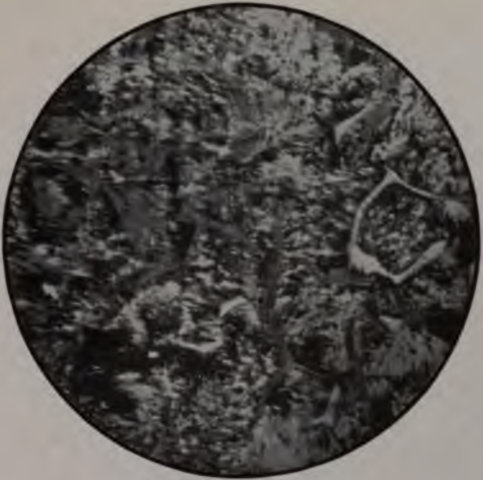

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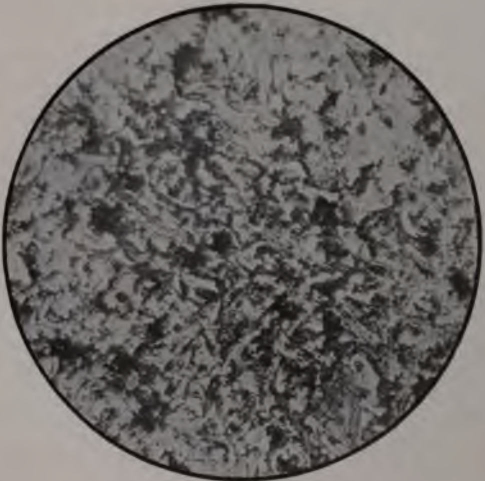

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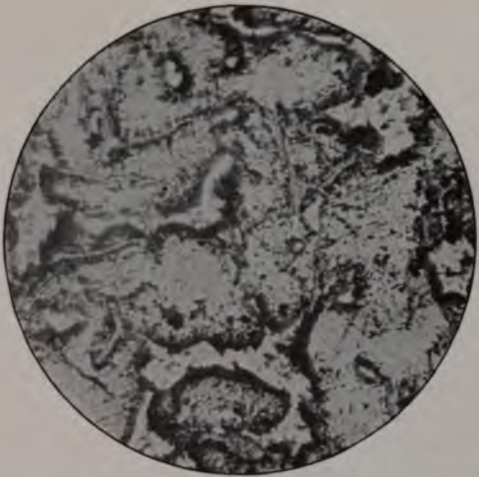

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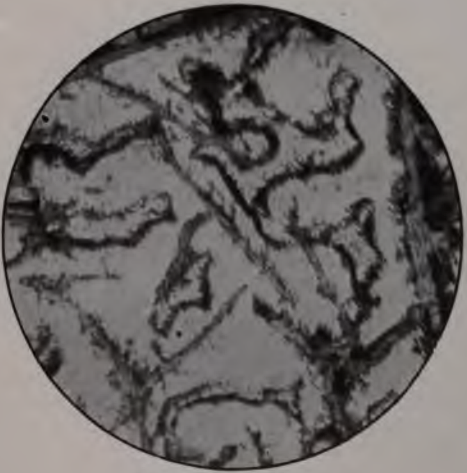

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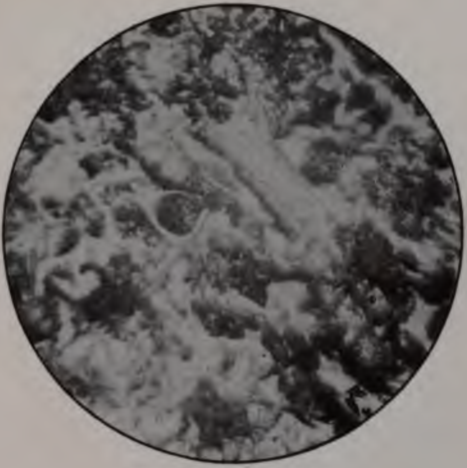

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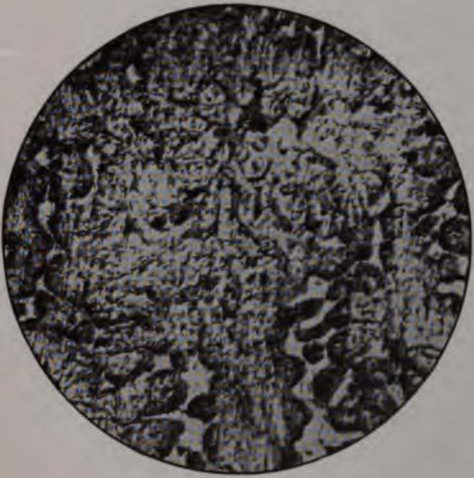

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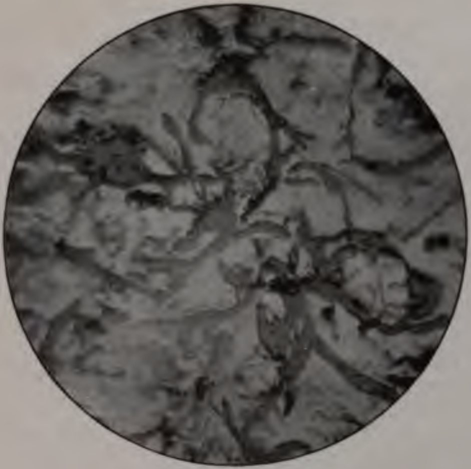

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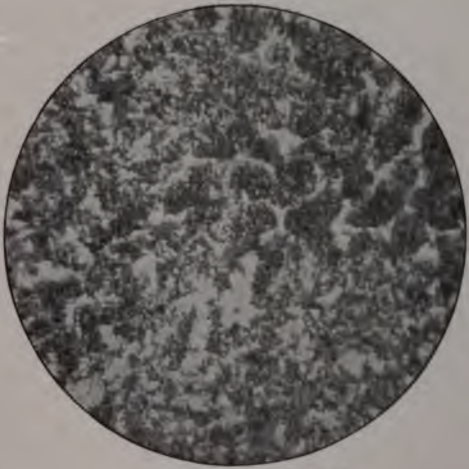

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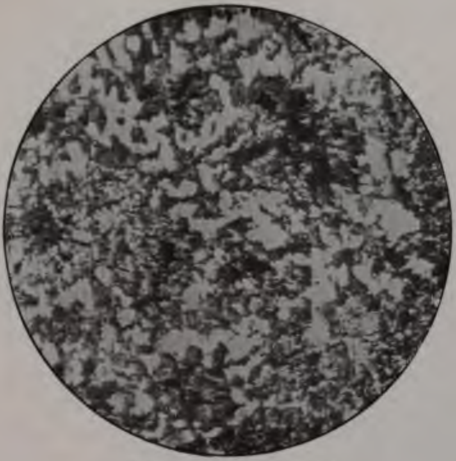

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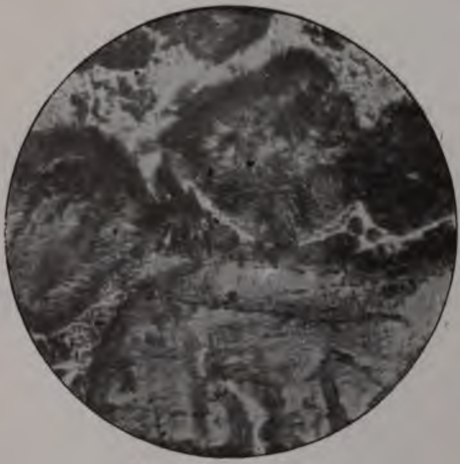

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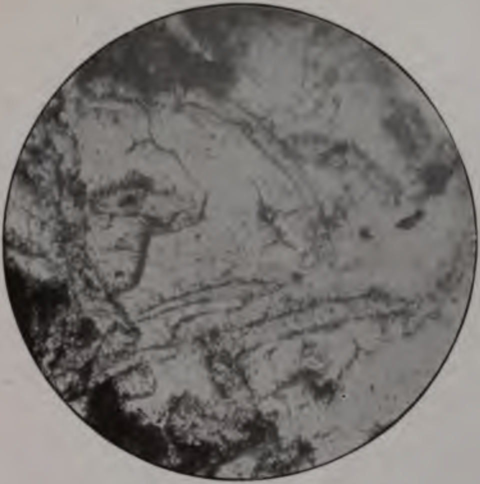

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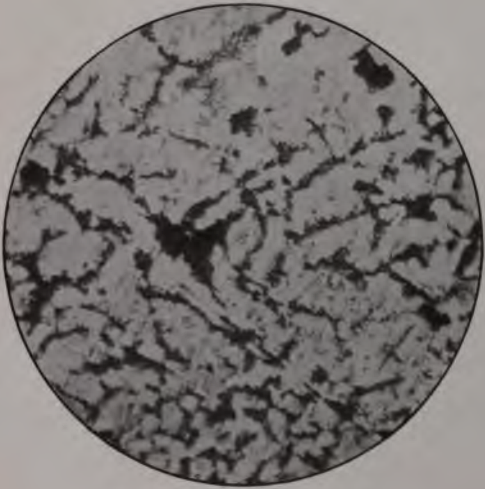

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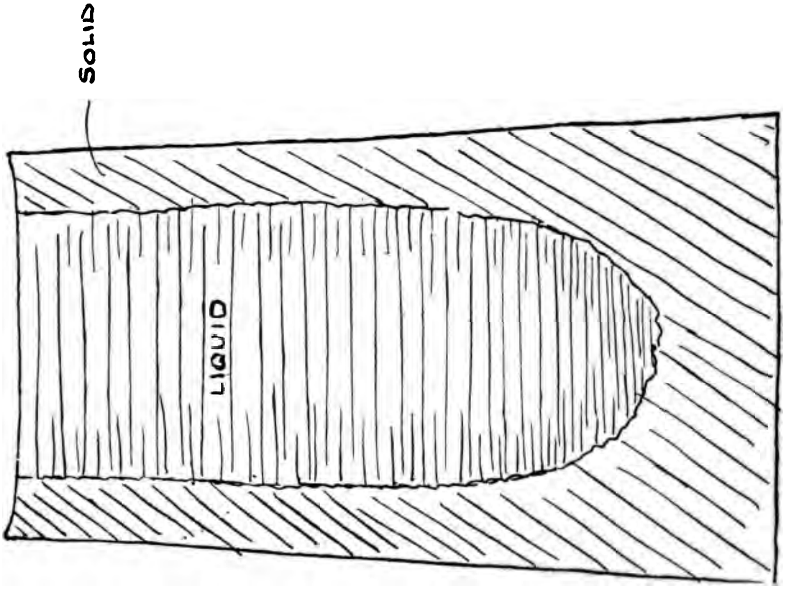

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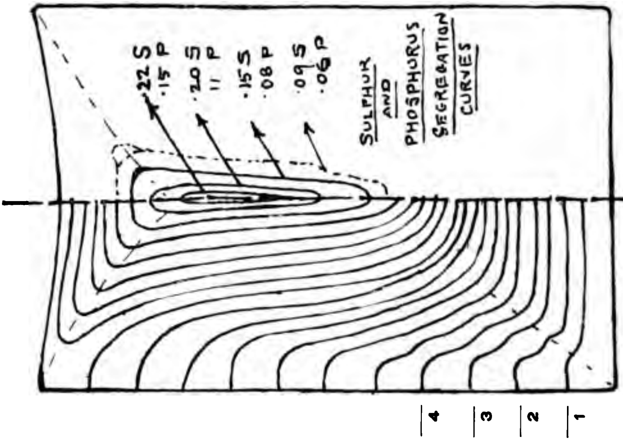

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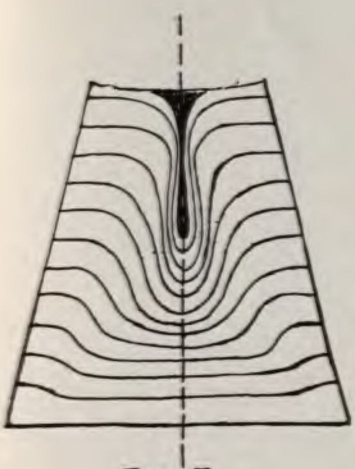

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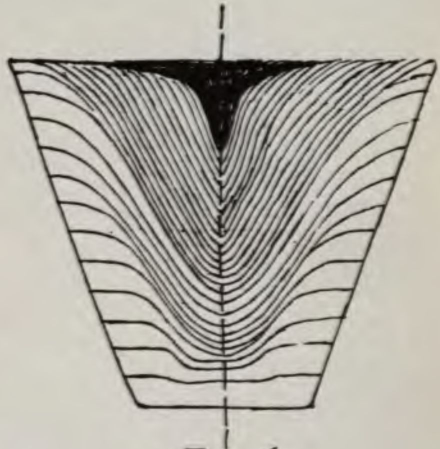

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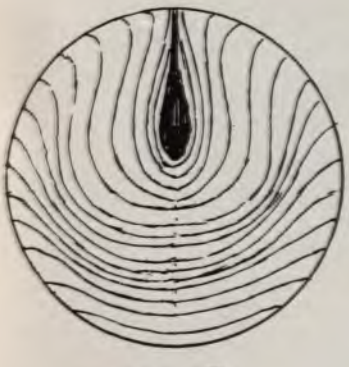

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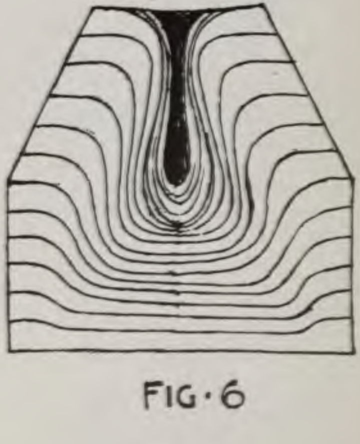

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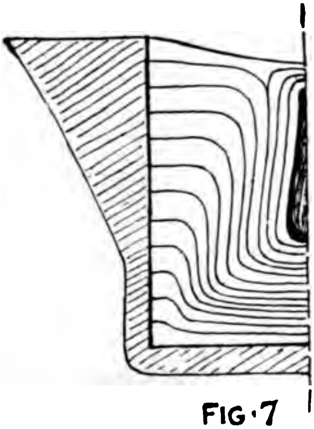

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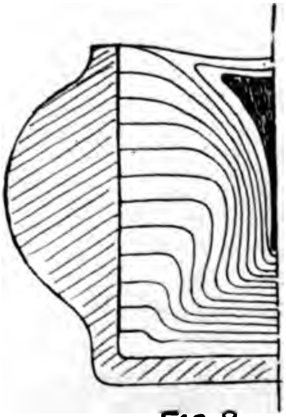

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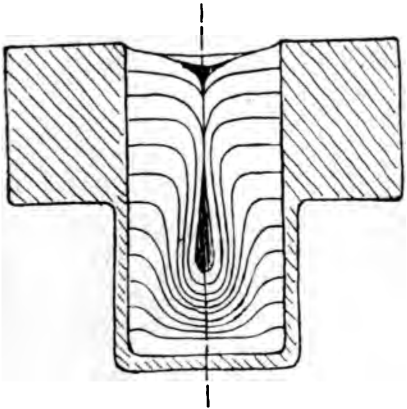

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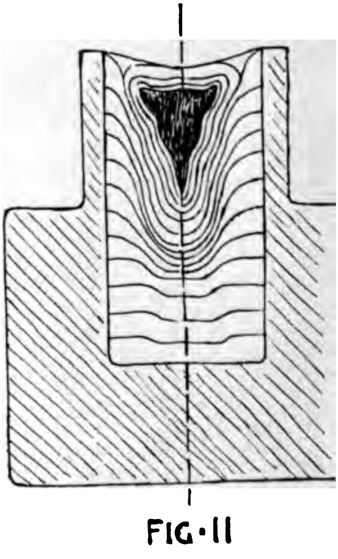

FIG·11

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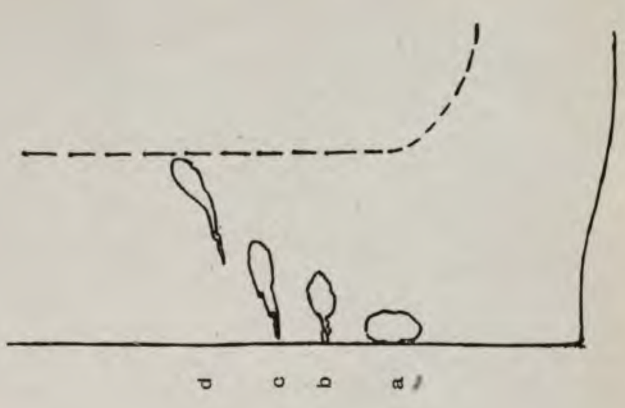

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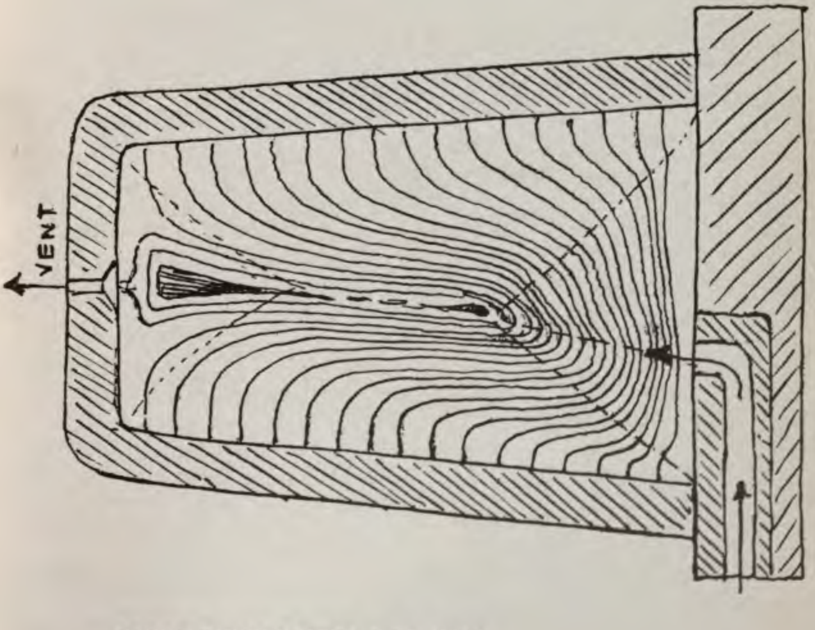

FIG. 13

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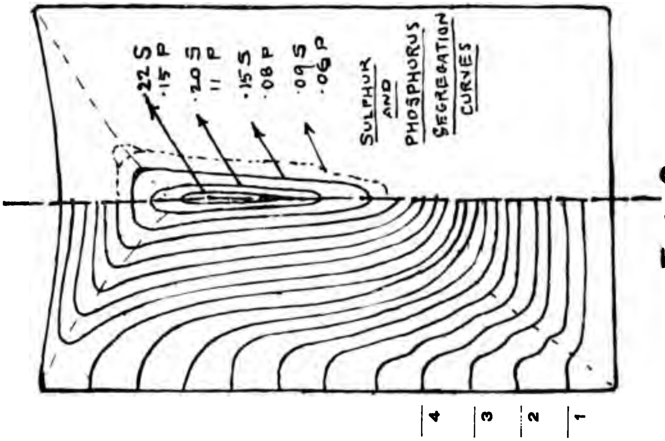

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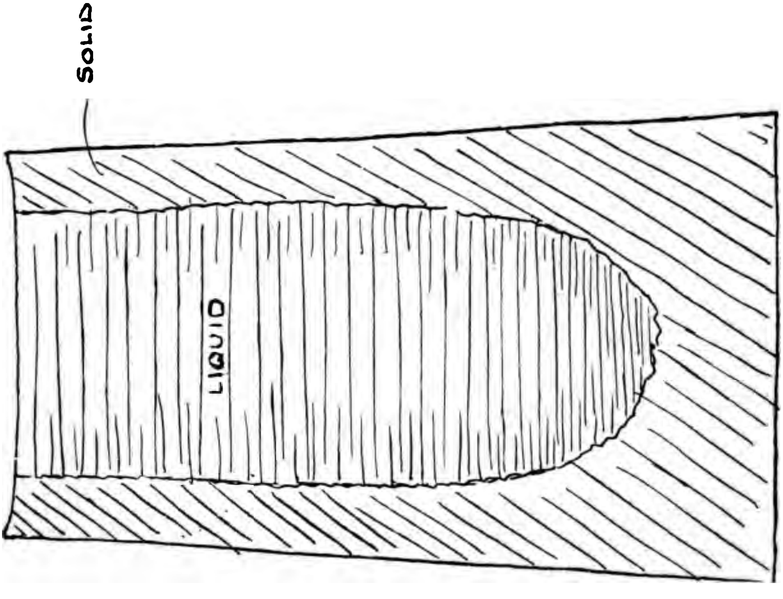

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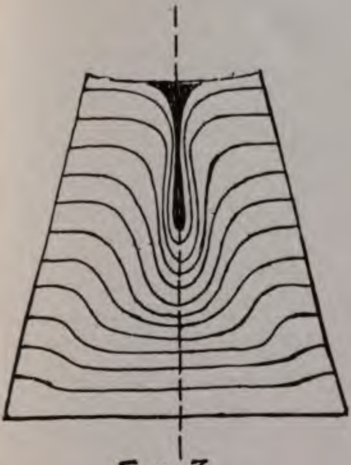

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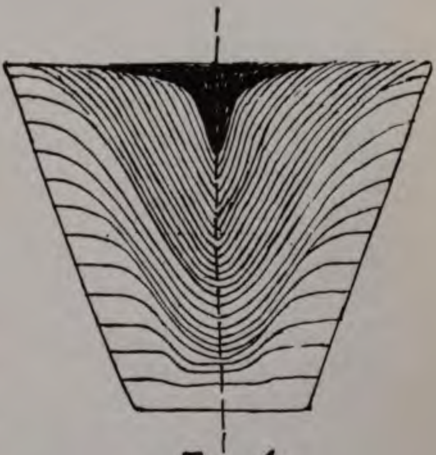

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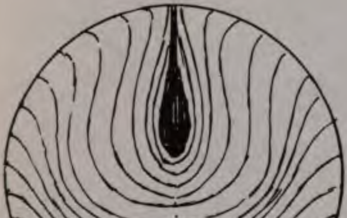

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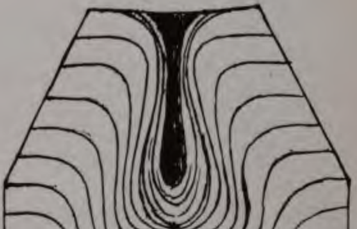

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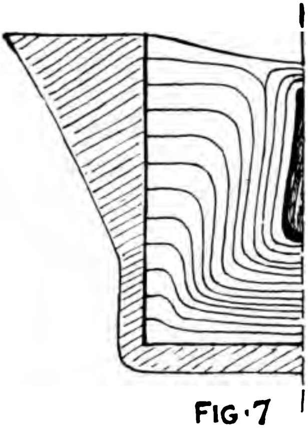

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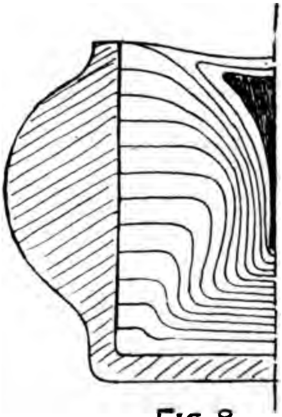

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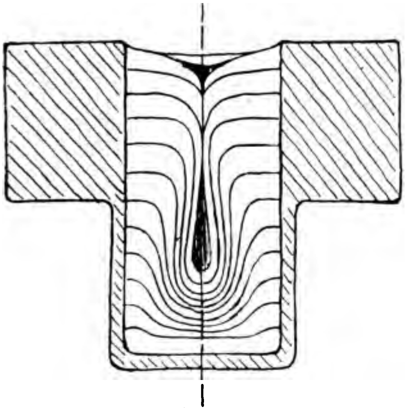

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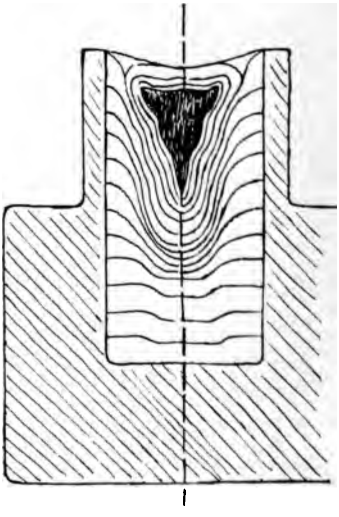

FIG·11

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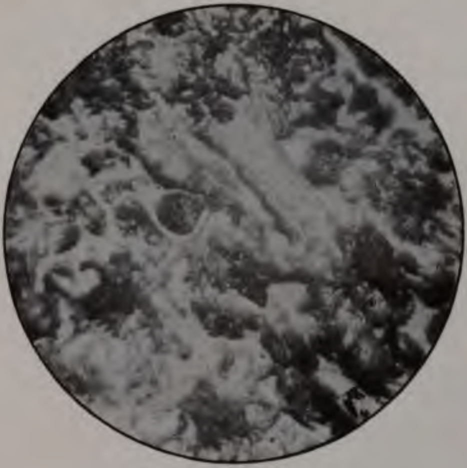

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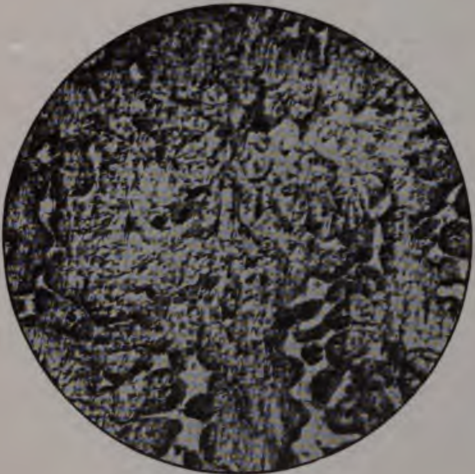

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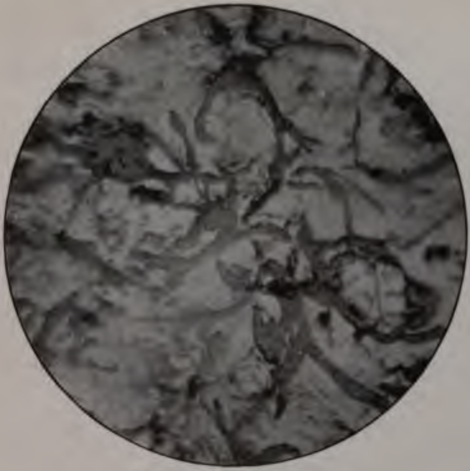

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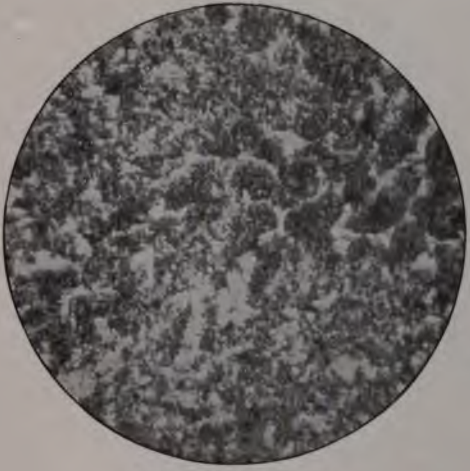

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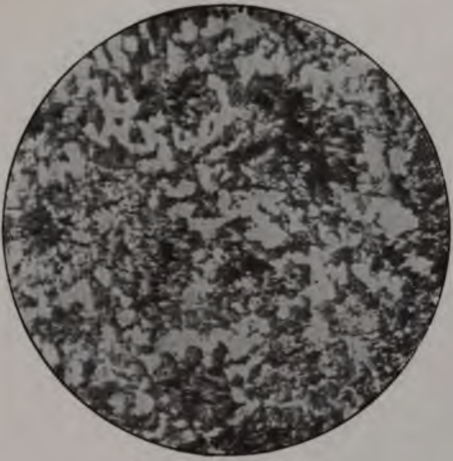

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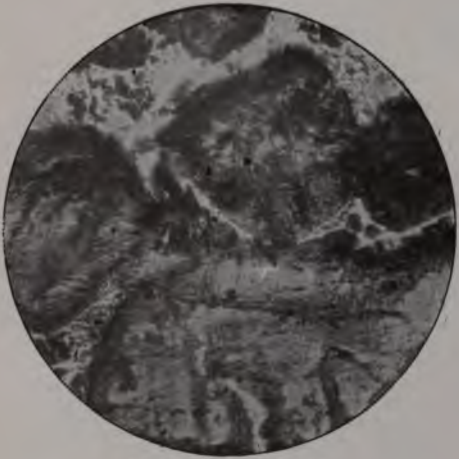

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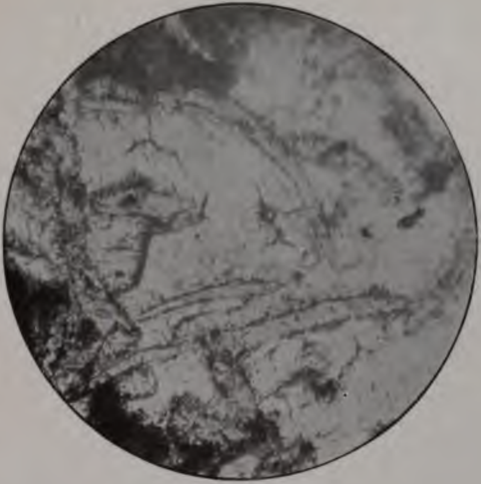

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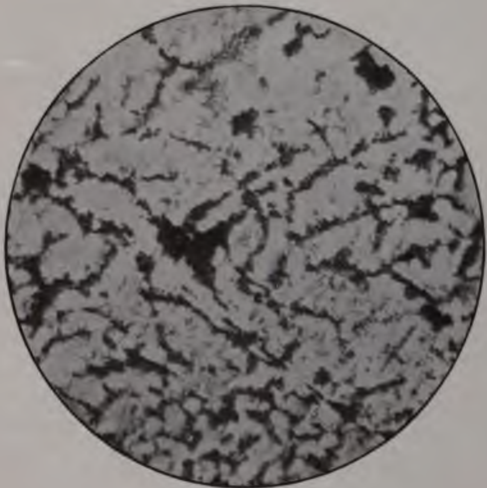


Micrograph No. 19.

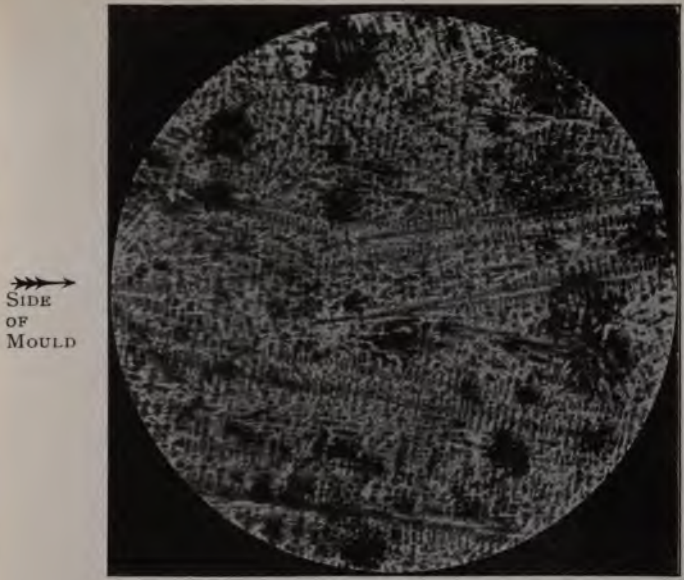


FIG. 24.

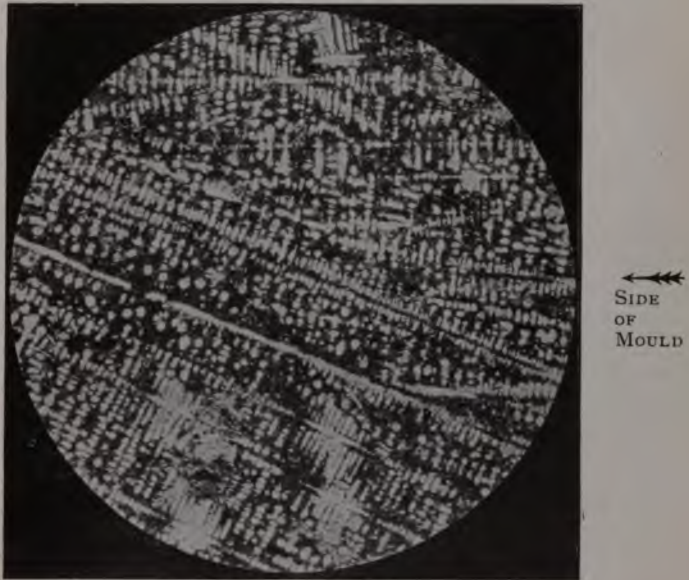


FIG. 25.

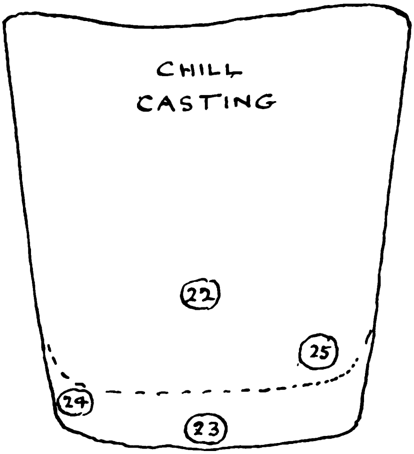
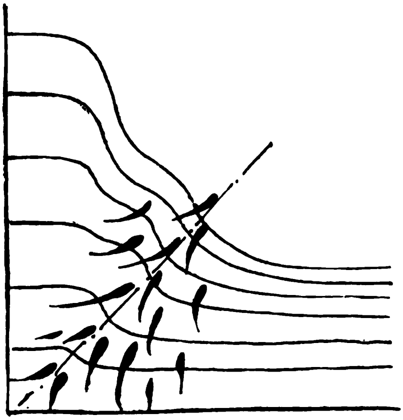


FIG 26

CARBON	COMBINED	·93	PER CENT
"	GRAPHITE	2·12	" "
SILICON		3·33	" "
MANGANESE		1·91	" "



FIG·28

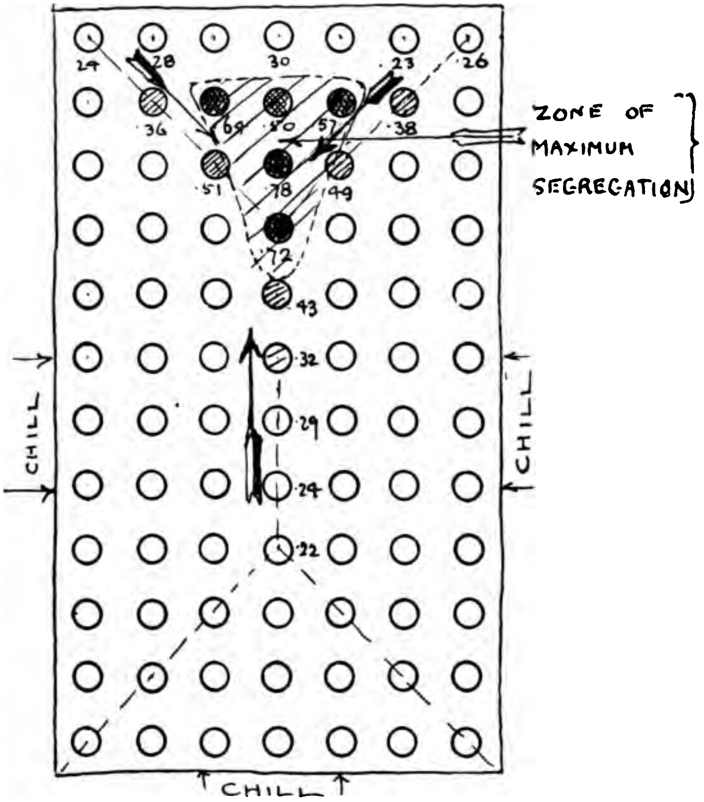


FIG. 27
CARBON CONTENT %
MARKED THUS ·22

Mr. J. E. Fletcher's Paper.

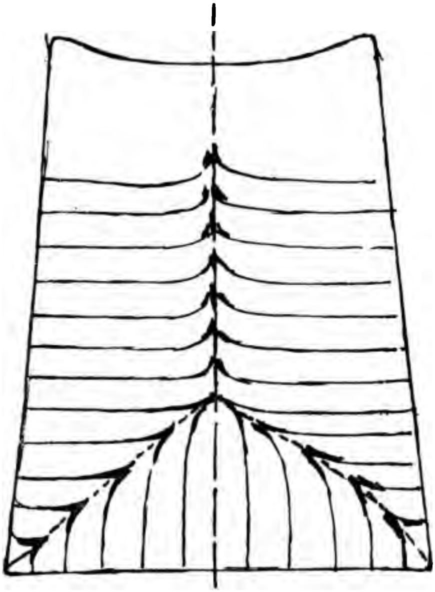


FIG. 29

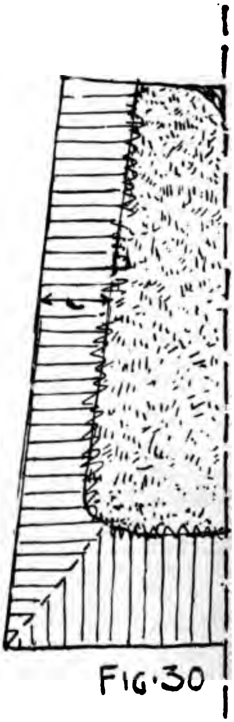
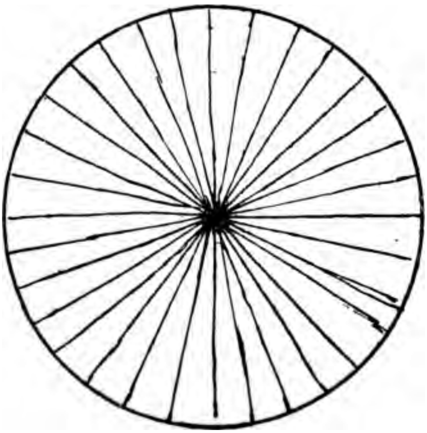
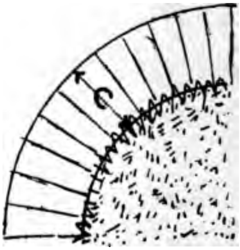


FIG. 30





Mr. J. E. Fletcher's Paper.

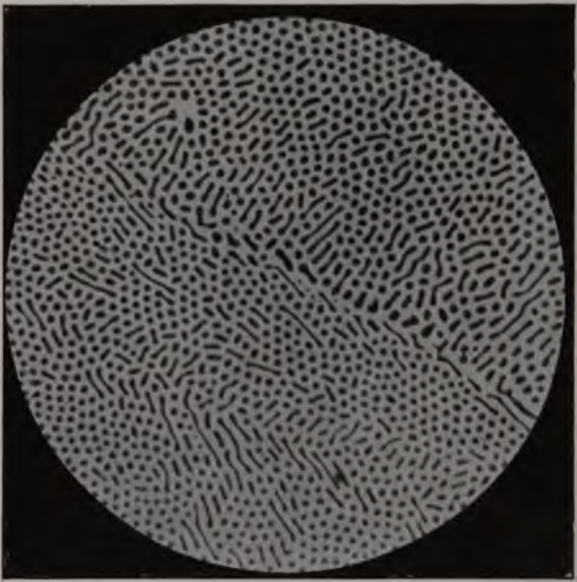
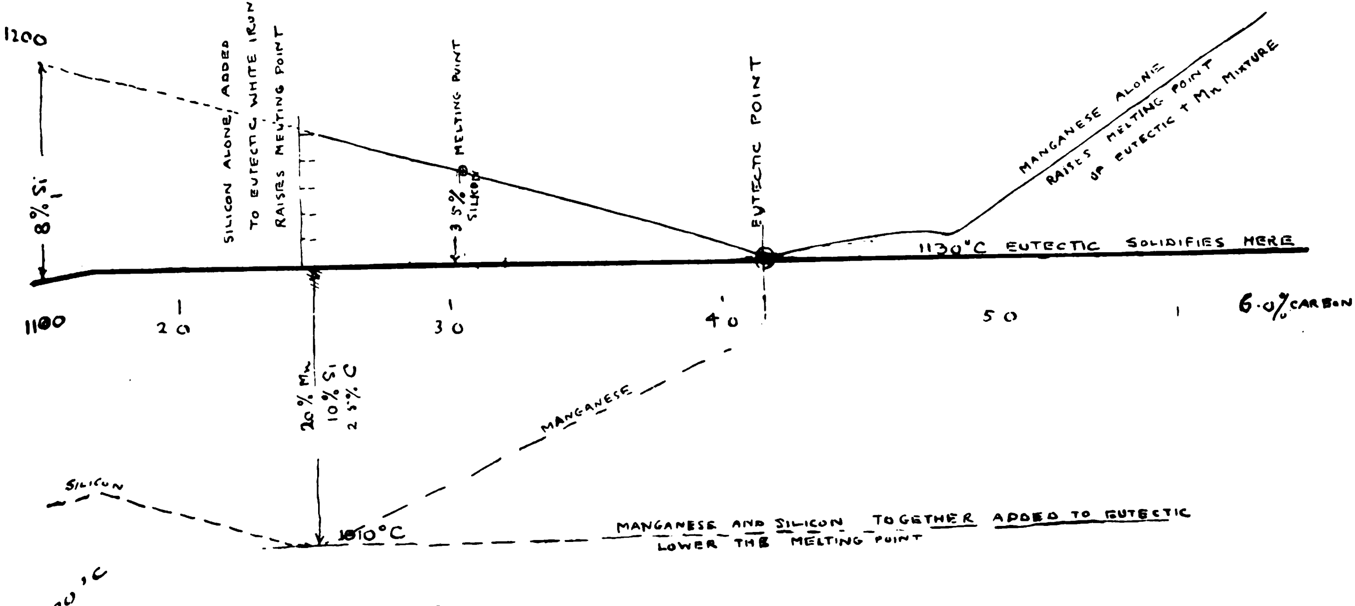


Fig. 32. Eutectic Formation in 20% Spiegeleisen.

Mr. J. E. Fletcher's Paper.

— FIG 33 —



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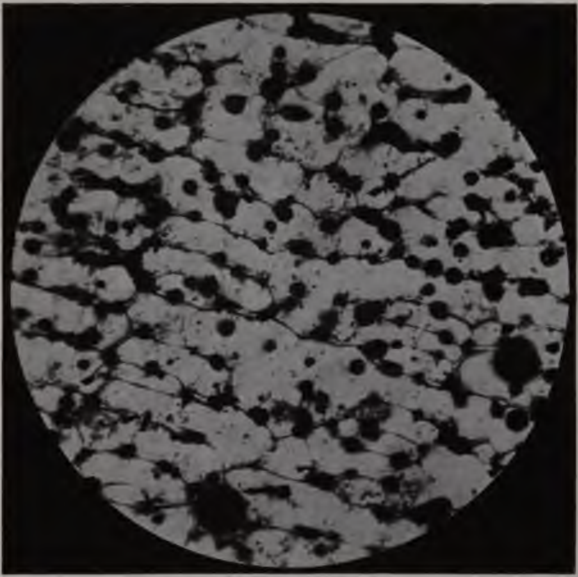

FIG. 35. GAS BUBBLES IN NICKEL-IRON ALLOY.

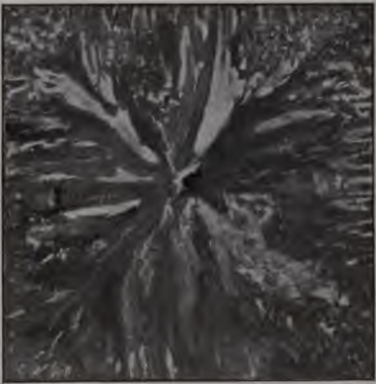

FIG. 36.
STEEL BAR ANNEALED IN LIME ('21% CARBON)
AT 700° COLUMNAR STRUCTURE REVEALED.

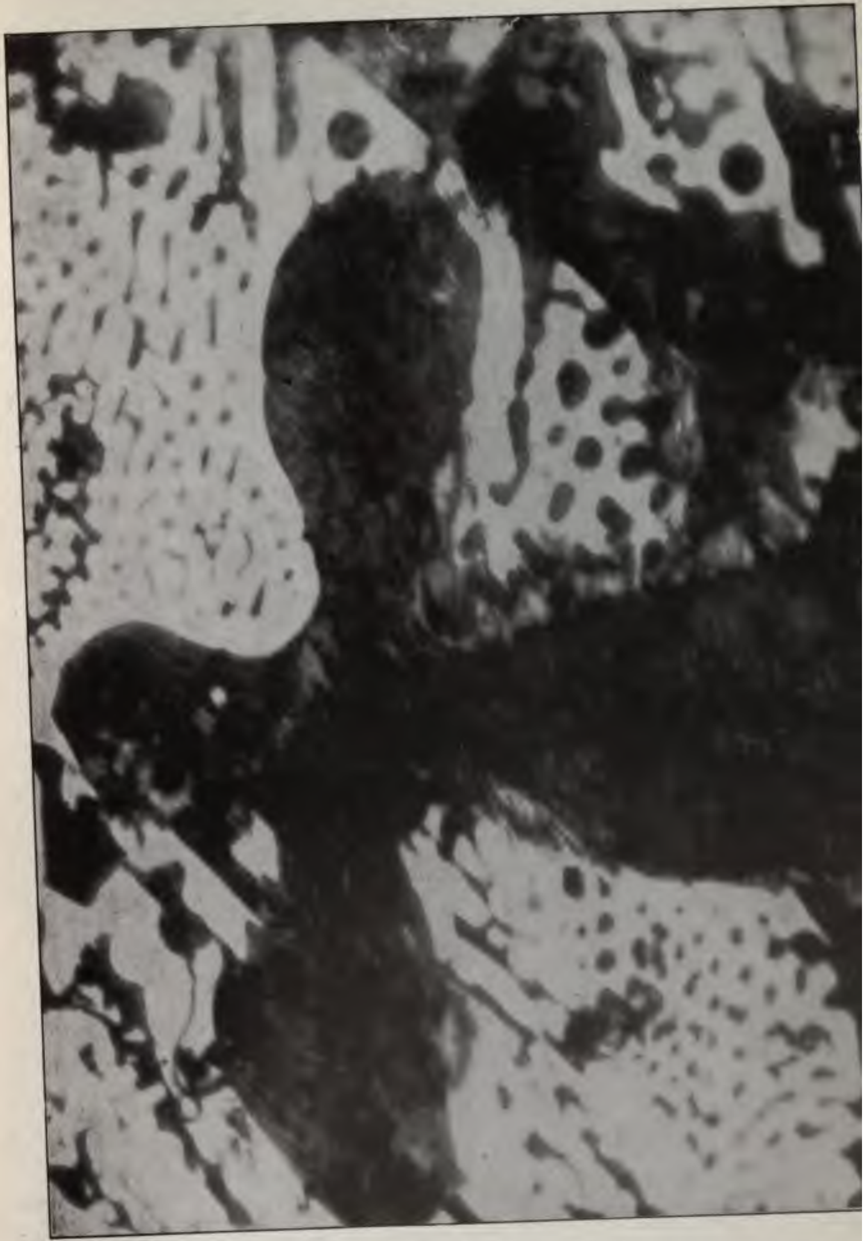

Fig. 37.

Carbonized Ferrite Crystallite in White Iron. 36% Carbon.

Mr. A. Jude's Paper.

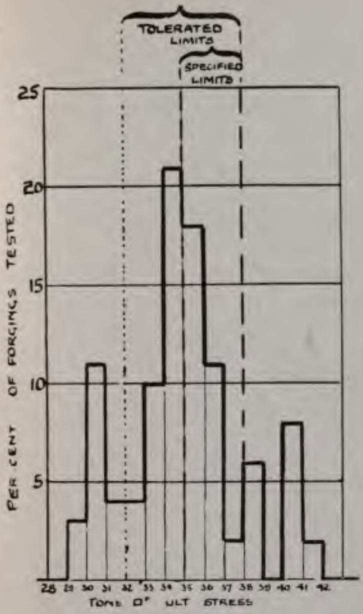

FIG. 1.

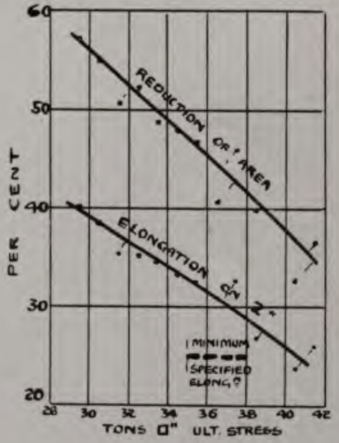

FIG. 2.

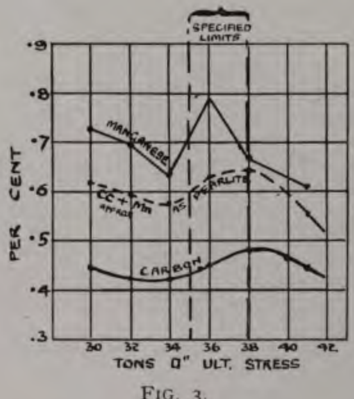

FIG. 3.

PROCEEDINGS STAFFS. I. & S. INST.
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Forgings arranged in order of impact strength

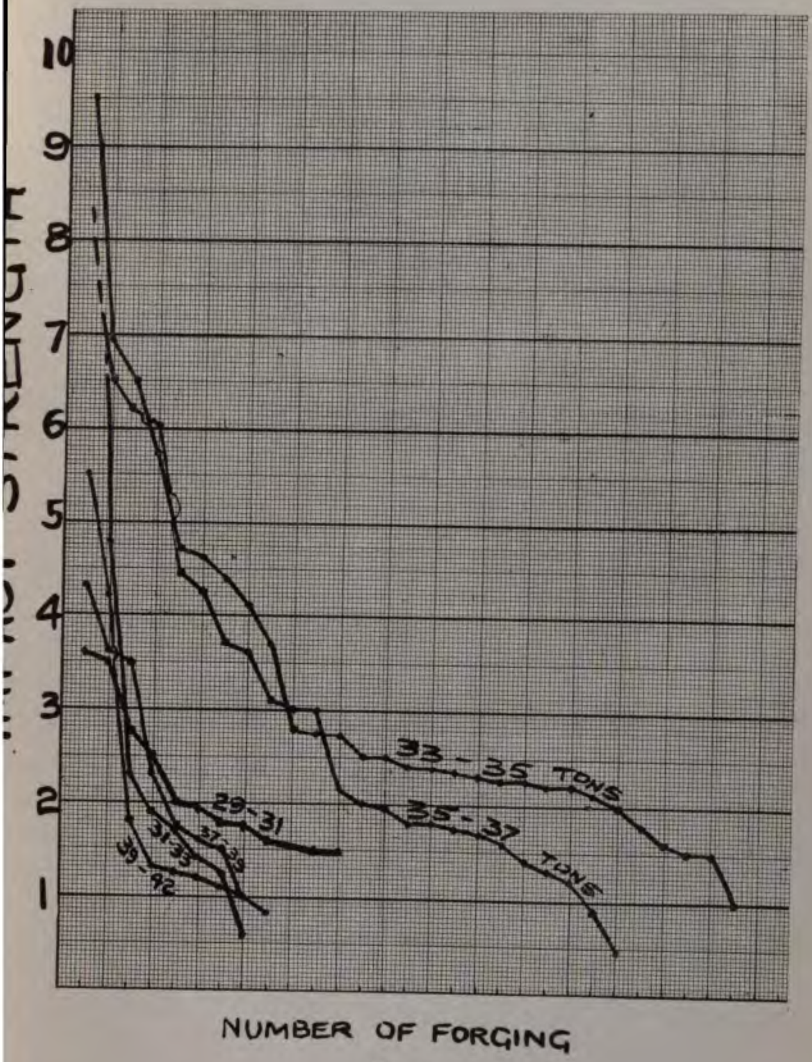


FIG 4.

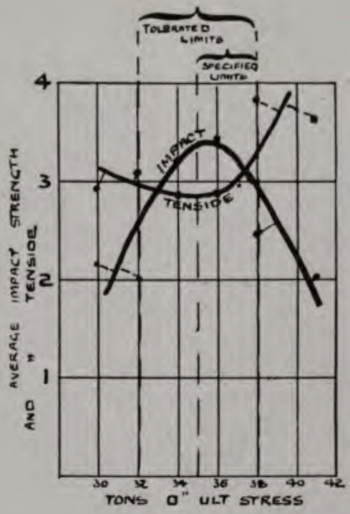

TOLERATED LIMITS
SPECIFIED LIMITS
4
3
2
1
AVERAGE IMPACT STRENGTH AND " TENSILE
IMPACT
TENSILE
30
32
34
36
38
40
42
TONS □" ULT STRESS

FIG. 5.

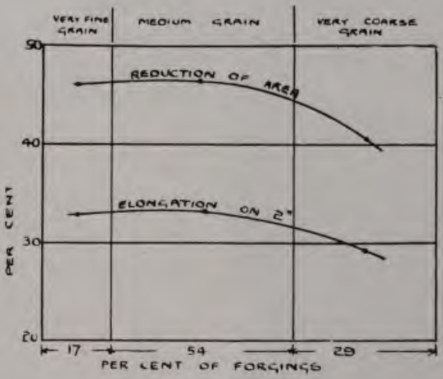

VERY FINE GRAIN
MEDIUM GRAIN
VERY COARSE GRAIN
50
40
30
20
PER CENT
REDUCTION OF AREA
ELONGATION ON 2"
17
54
29
PER CENT OF FORGINGS

FIG. 8.

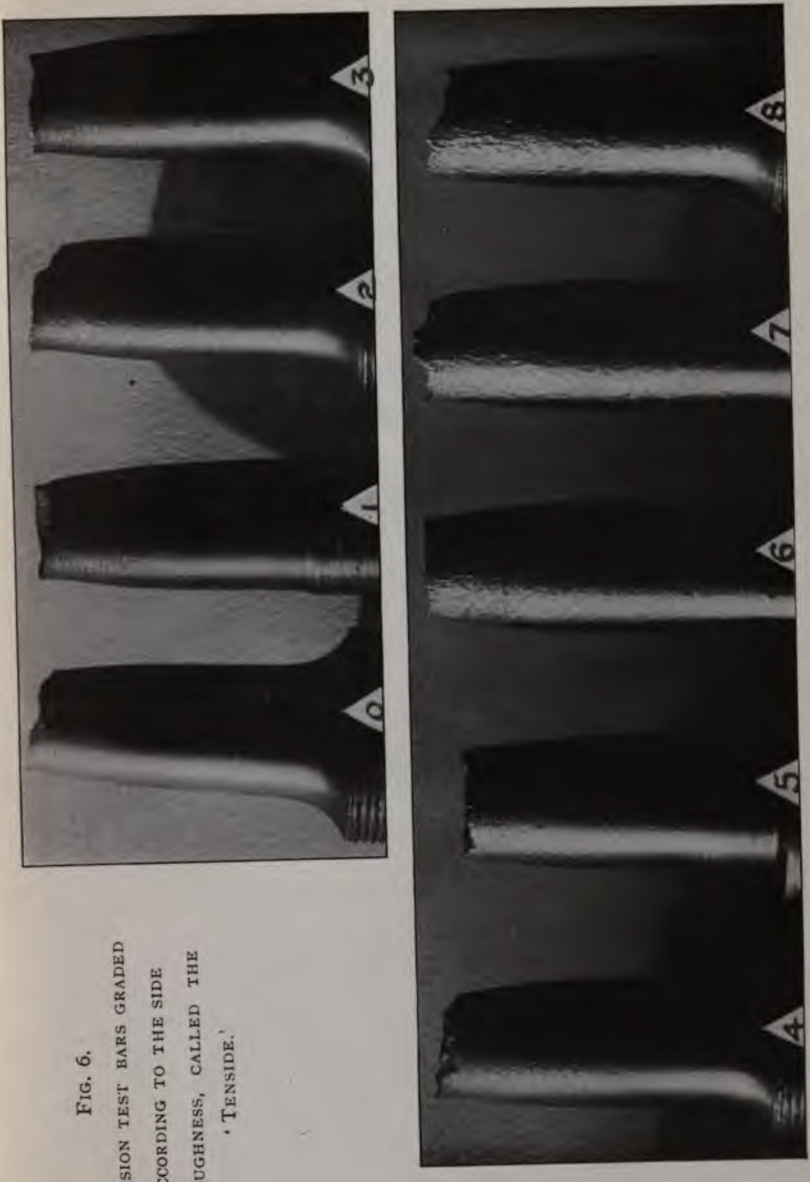
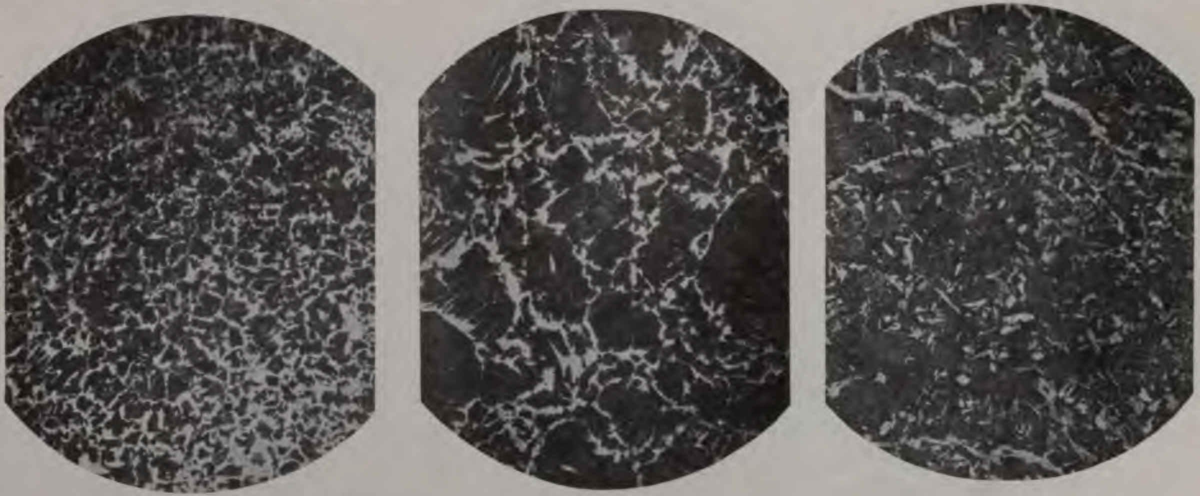


Fig. 6.

Tension test bars graded according to the side roughness, called the 'Tenside.'

Mr. A. Jude's Paper.

FIG. 7. EXAMPLES OF THE RELATION BETWEEN MICRO-STRUCTURE AND MECHANICAL PROPERTIES OF HARD MILD STEEL.



Fine grain × 35 diams.

Medium grain × 35 diams.

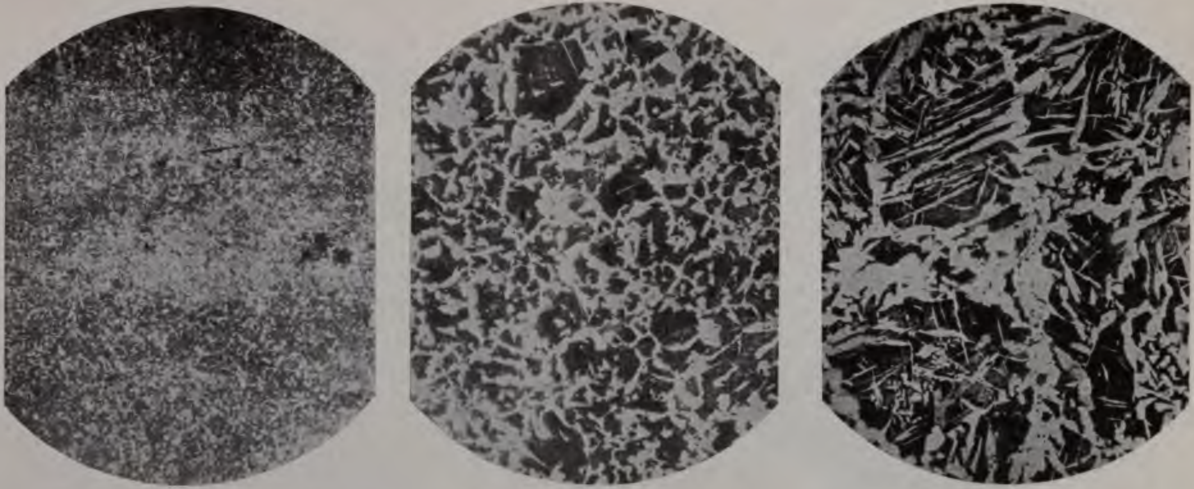
Coarse grain × 35 diams

The grain is so gross here that barely one shows in the field.

	Fine grain	Medium grain	Coarse grain
Ult. Tensile	40·1 Tons	39·4 Tons	40·84 Tons.
Elong. 2 in. ..	28 per cent.	25 per cent.	Broke short, a common occurence.
Reduc. Area ..	40 ,, ,,	36 ,, ,,	
Tenside	0	·3	
Impact	5·5	4·5	1·1.

Mr. A. Jude's Paper.

FIG. 7A. EXAMPLES OF THE RELATION BETWEEN MICRO-STRUCTURE AND MECHANICAL PROPERTIES OF MEDIUM GRADE MILD STEEL.



Fine grain × 35 diams.

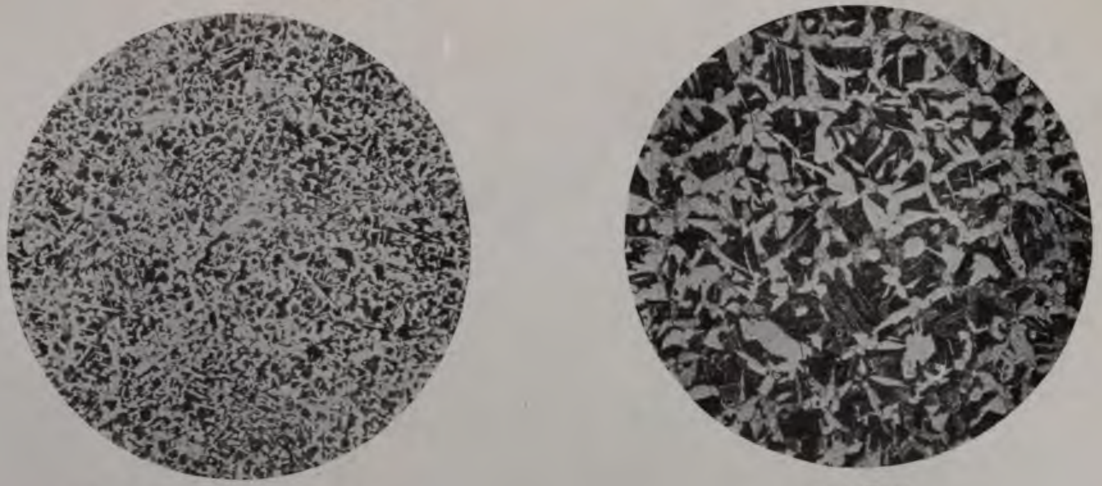
Medium grain × 35 diams.

Coarse grain × 35 diams.

Ult. Tensile	..	35·5 Tons	37·5 Tons	36·1 Tons.
Elong. 2 ins.	..	32·5 per cent.	29·5 per cent.	30·5 per cent.
Reduc. Area	..	46·8 ,, ,,	38 ,, ,,	43·5 ,, ,,
Tenside ..	..	0	2	6
Impact ..	..	6·5	3·8	2·15

PROCEEDINGS STAFFS. I. & S. INST.
SESSION 1907-1908.

FIG. 7B. EXAMPLES OF THE RELATION BETWEEN MICRO-STRUCTURE AND MECHANICAL PROPERTIES OF SOFT MILD STEEL.



Fine grain × 35 diams.

Coarse grain × 35 diams.

		Fine grain	Coarse grain
Ult. Tensile	..	34·9 tons.	33·6 Tons.
Elong 2 ins.	..	34 per cent.	34 per cent.
Reduc. Area	..	47 ,, ,,	46 ,, ,,
Tenside ..	..	0	3
Impact ..	..	6·9	1·6

Mr. J. Butler's Paper on Concrete Bricks.

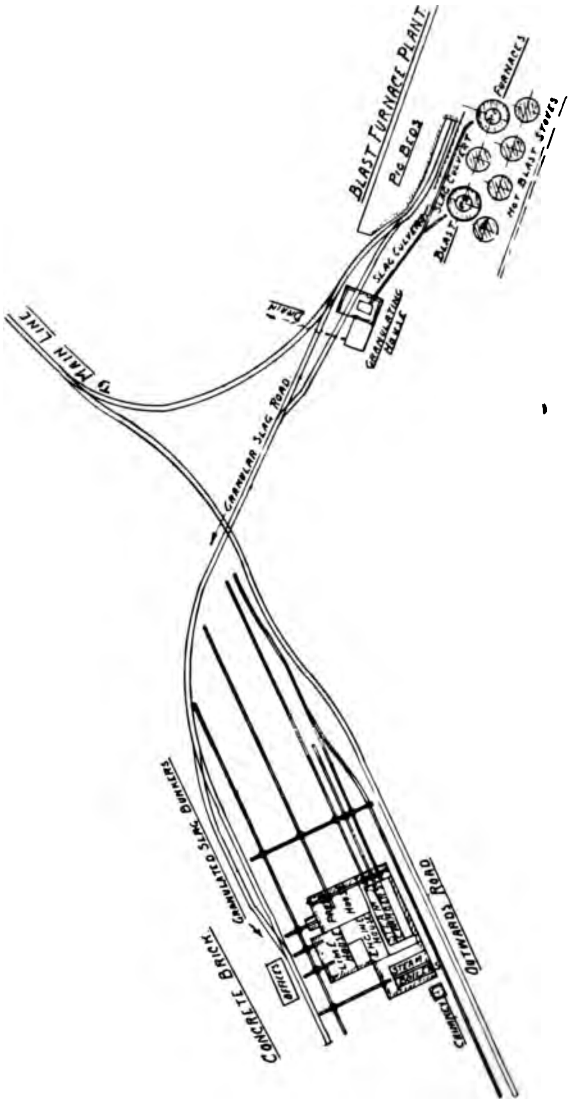


Fig. 1.
General Arrangement of Brick Works and Blast Furnace Plant.

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SESSION 1907-1908.

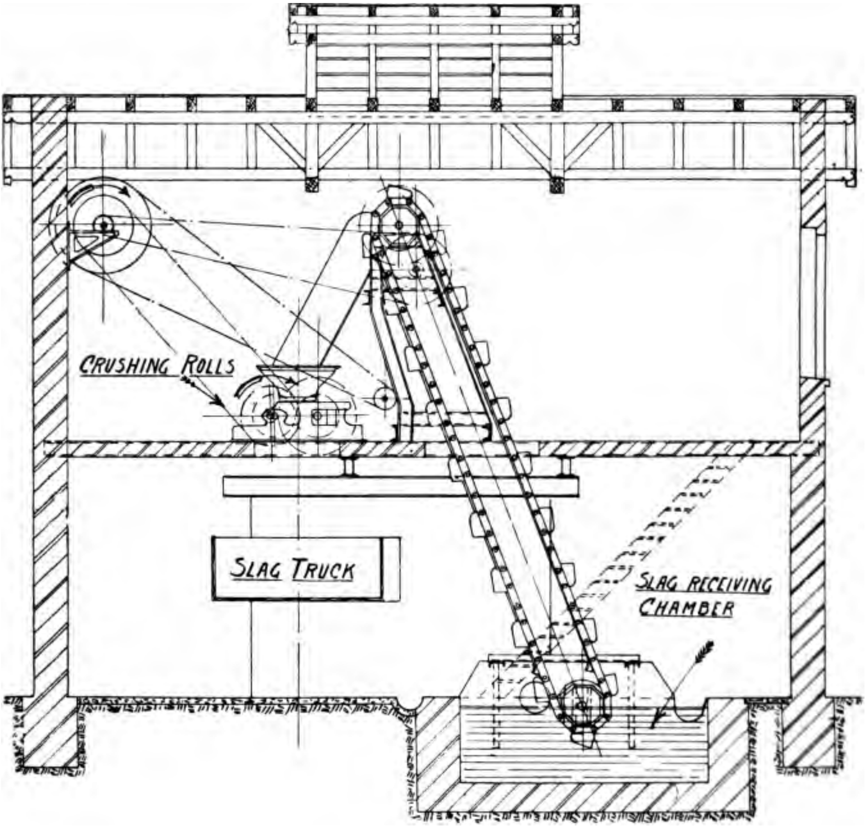

FIG. 3.

GRANULATING HOUSE.—SECTIONAL ELEVATION.

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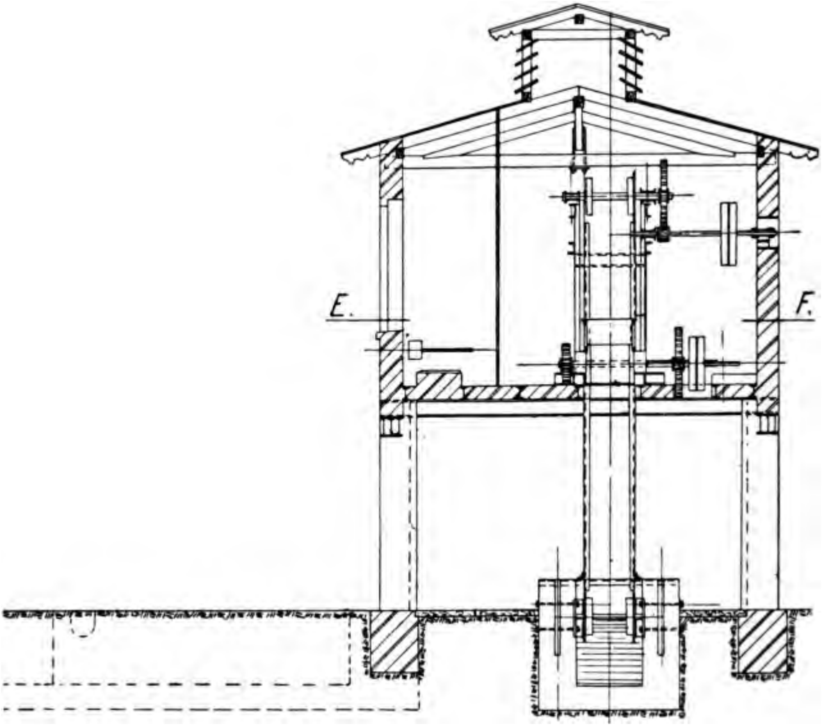

Fig. 4.

Granulating House.

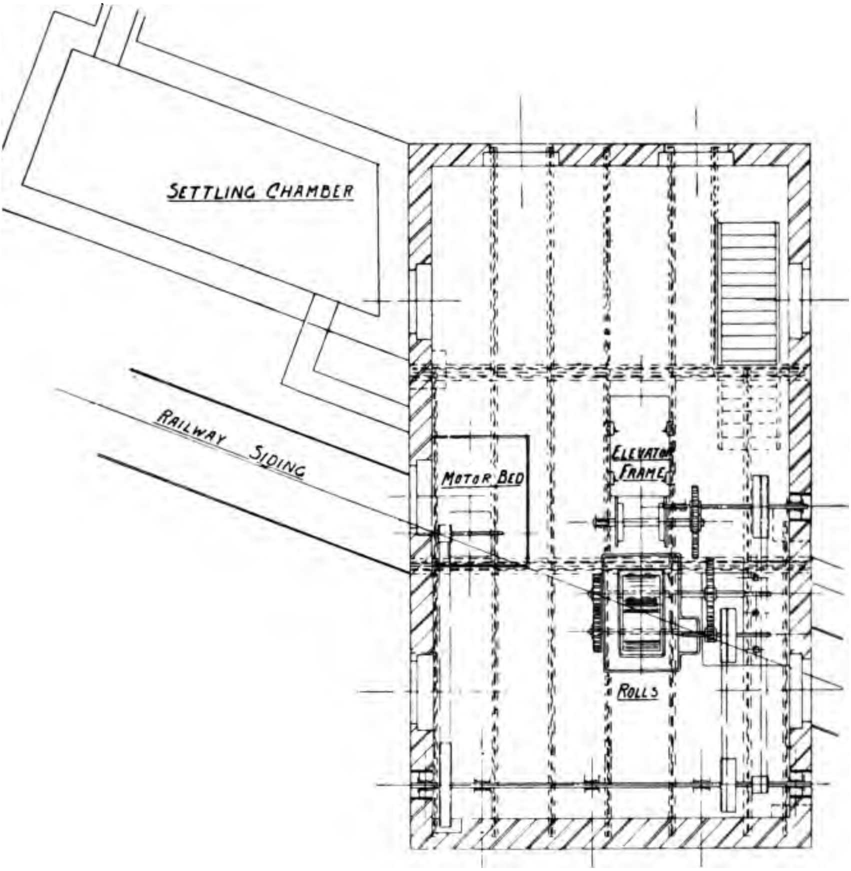

Fig. 5.

Sectional Plan of Granulating House.

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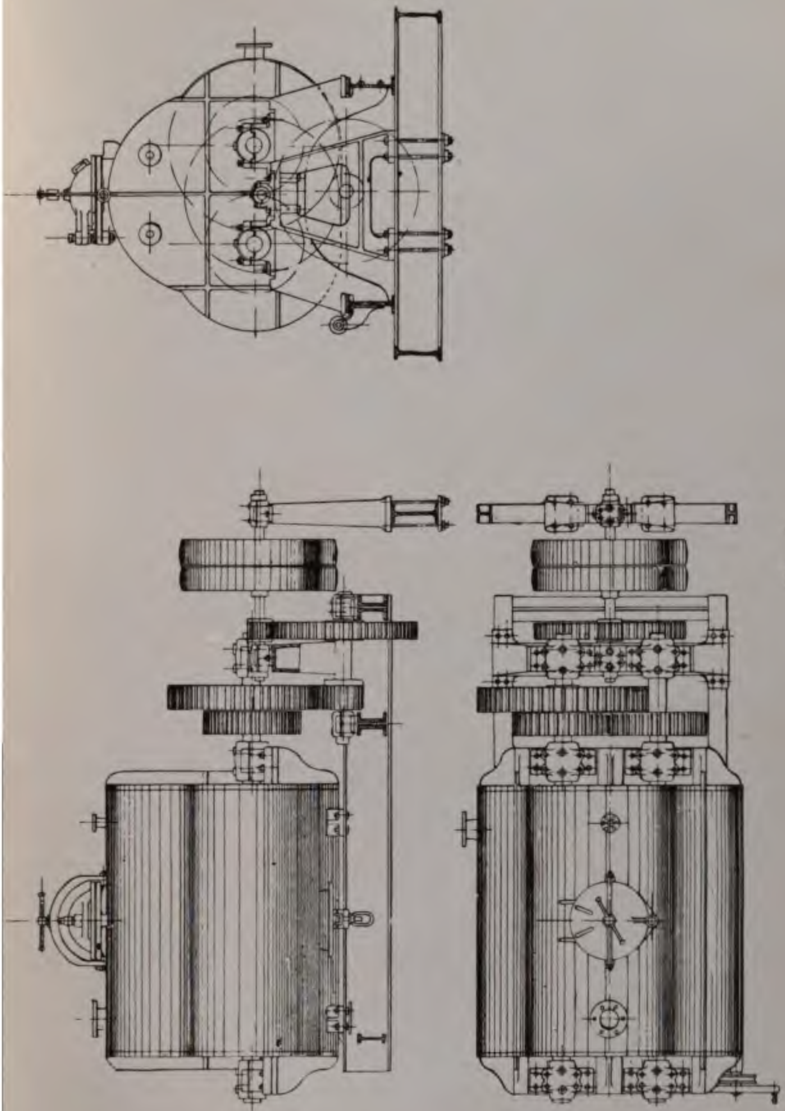
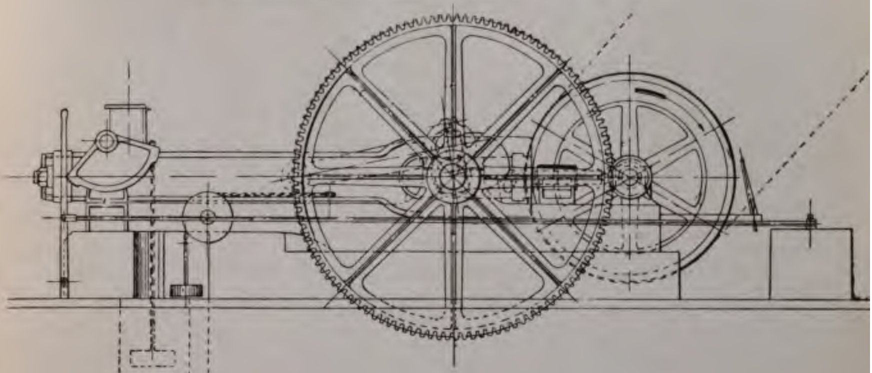


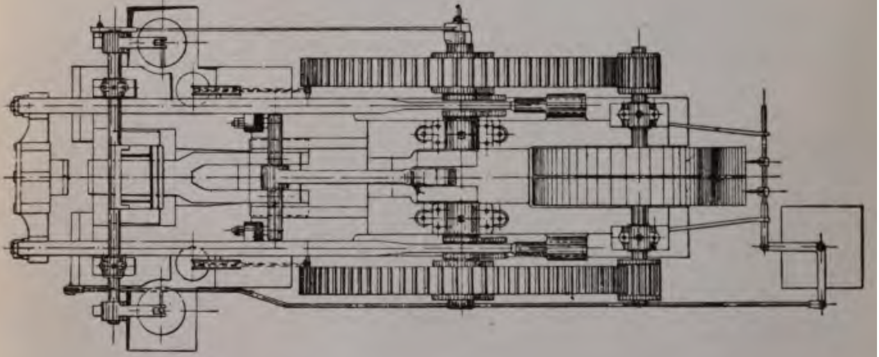
FIG. 6.
PREPARING MACHINE.

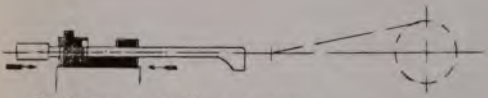
PROCEEDINGS STAFFS. I. & S. INST.
SESSION 1907-1908.

FIG. 7.

PRESS FOR CONCRETE SLAG BRICKS.—ELEVATION.



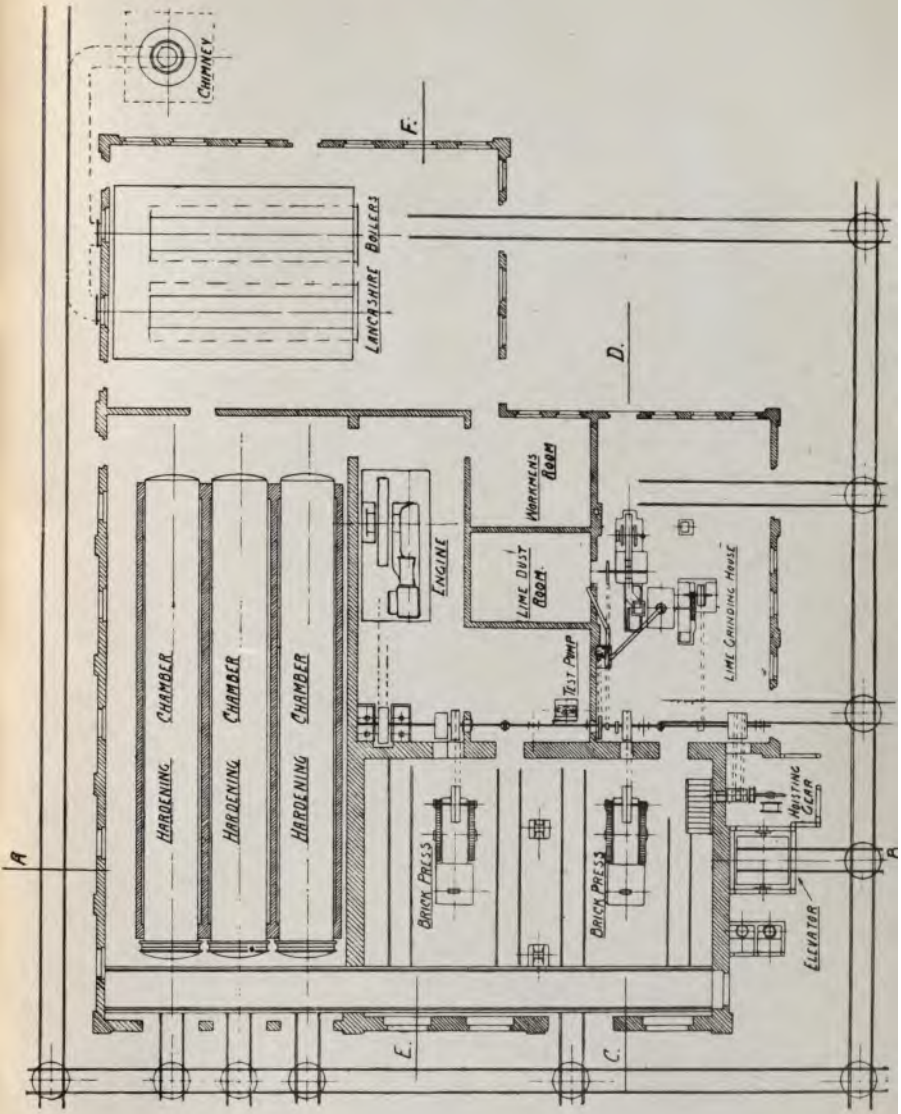




Section through the Press-mould.

GROUND PLAN.

Mr. J. Butler's Paper on Concrete Bricks.



PROCEEDINGS STAFFS. I. & S. INST.
SESSION 1907-1908.

Mr. J. Butler's Paper on Concrete Bricks.

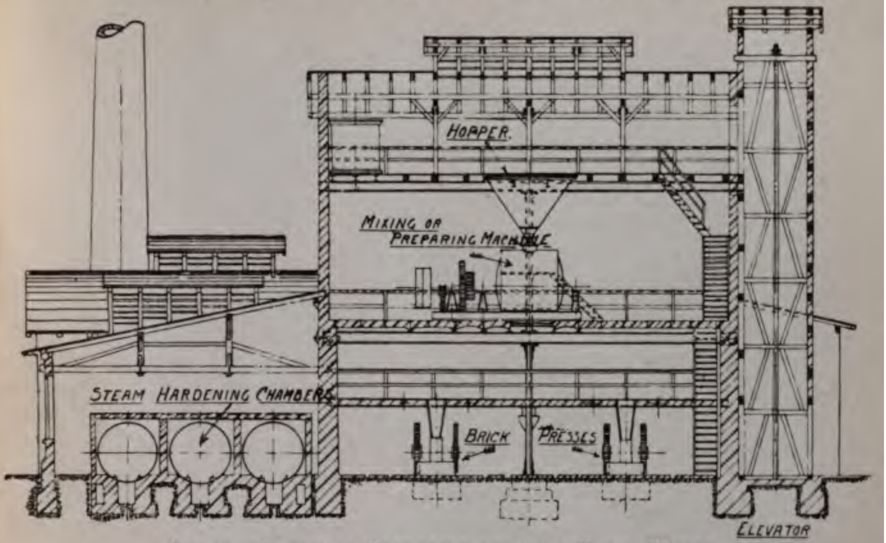


FIG. 9.—SECTIONAL ELEVATION THROUGH BRICK WORKS.

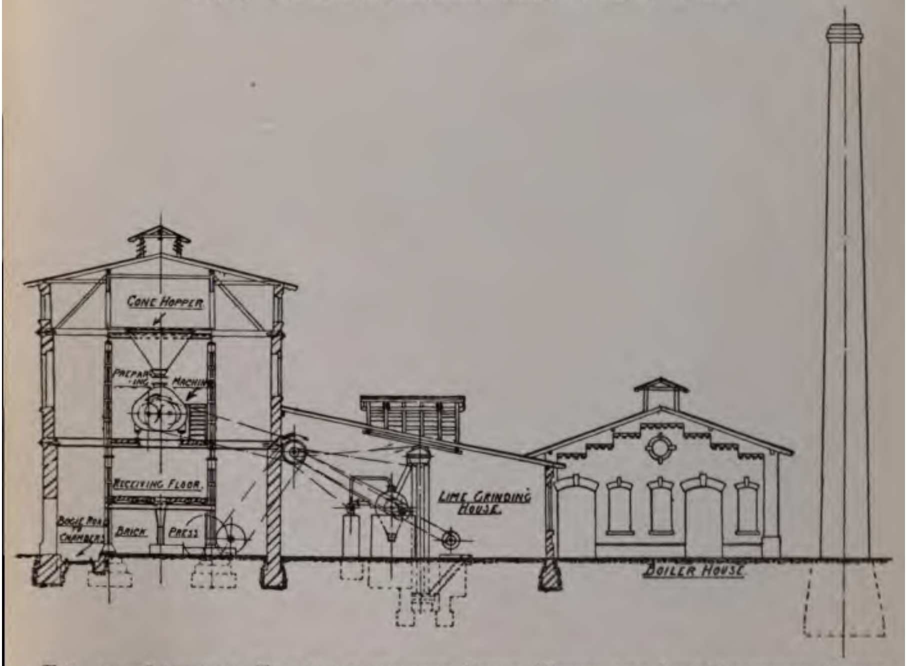


FIG. 10.—SECTIONAL ELEVATION THROUGH BRICK WORKS AND LIME CRUSHING HOUSE.

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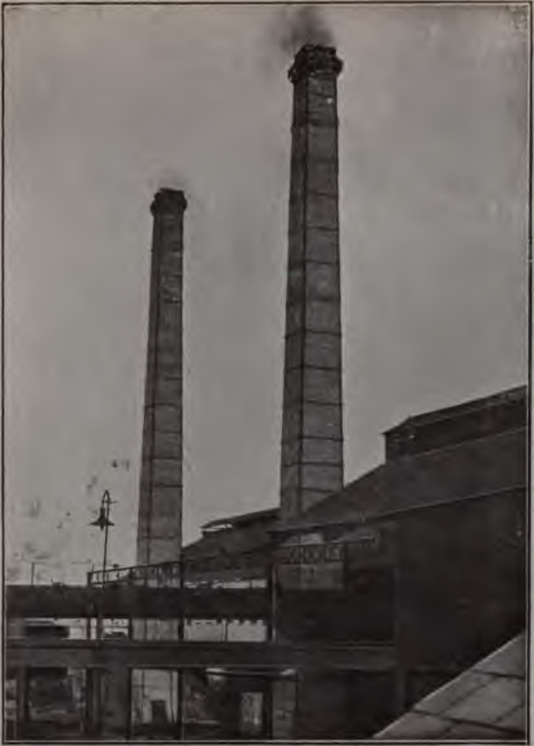
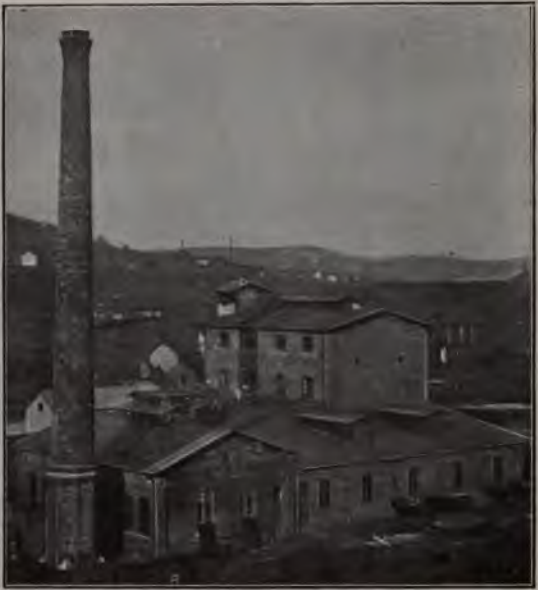
SESSION 1907-1908.

Mr. J. Butler's Paper on Concrete Bricks.



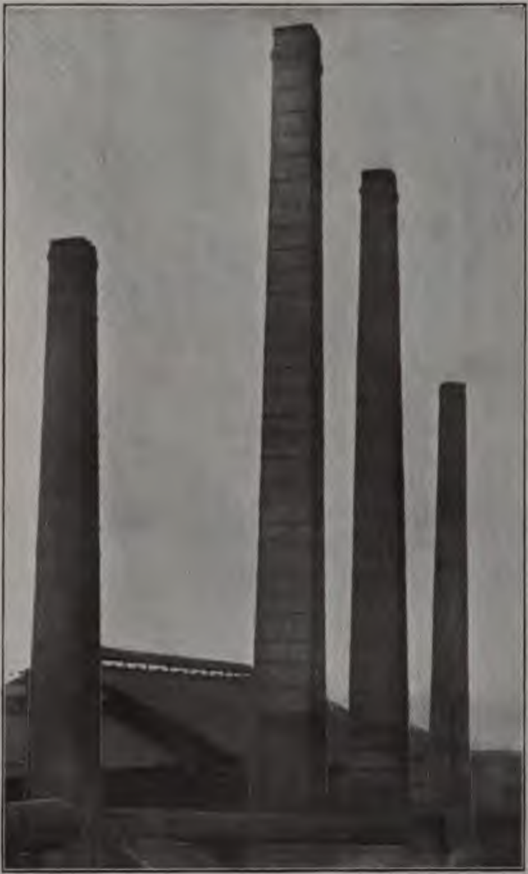
Chimneys 100 feet high, by 3ft. 6in. square. Built of Bricks made from Blast Furnace Slag. August, 1906.



General view of Slag Concrete Brick Works. Built of Bricks made from Slag. October, 1907.

PROCEEDINGS STAFFS. I. & S. INST.
SESSION 1907-1908.

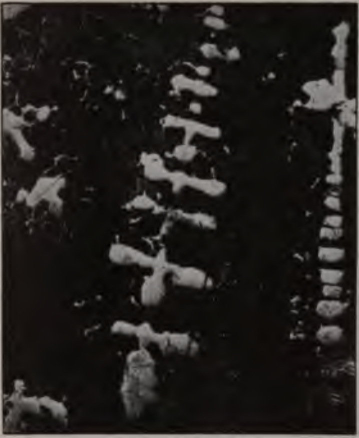
Mr. J. Butler's Paper on Concrete Bricks.



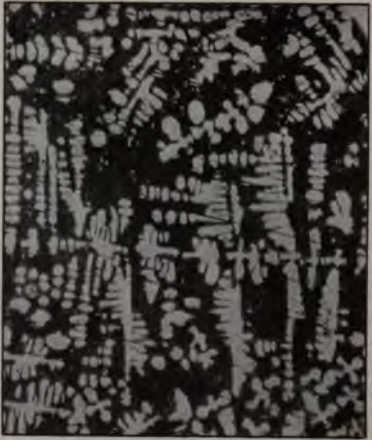
The Large Chimney, built of bricks made from Blast Furnace Slag. Height 150 feet, by 5 feet square inside. February, 1907.

PROCEEDINGS STAFFS. I. & S. INST
SESSION 1907-1908.

Mr. J. E. Stead's Paper.



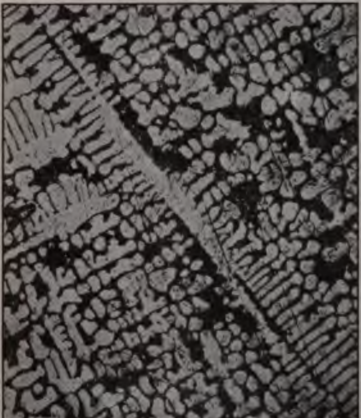
No. 1.



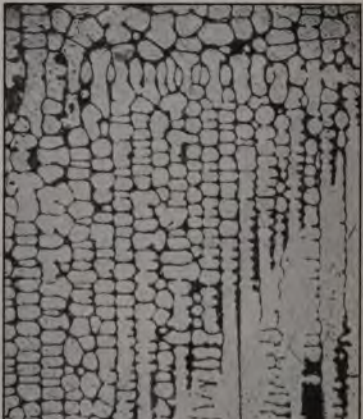
No. 2.

	No. 1.	No. 2.
Iron Crystallites ..	10·0% ..	52·7%
Iron Sulphide ..	90·0 ..	47·3

Magnified 50 diameters.



No. 3.

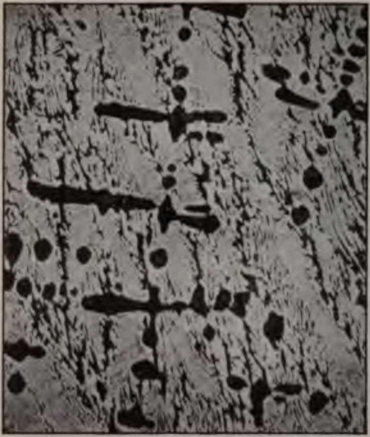


No. 4.

	No. 3.	No. 4.
Iron Crystallites ..	76·9% ..	88·45%
Iron Sulphide ..	23·1 ..	11·55

Magnified 50 diameters.

Mr. J. E. Stead's Paper.

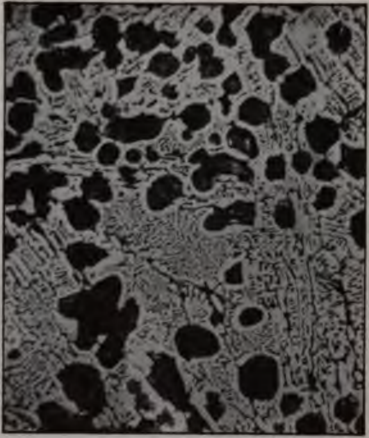


No. 5.

SWEDISH IRON.

Carbon	..	4·10%
Sulphur	..	0·02

Magnified 50 diameters.

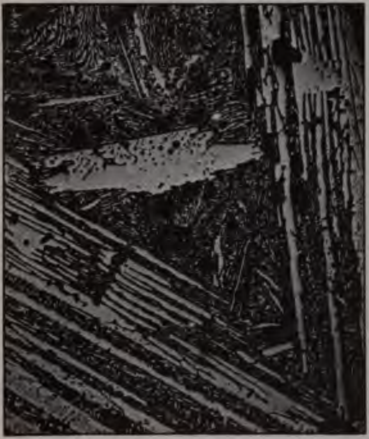


No. 6.

AMERICAN WASHED IRON.

Carbon	..	3·50%
Sulphur	..	0·02

Magnified 50 diameters.

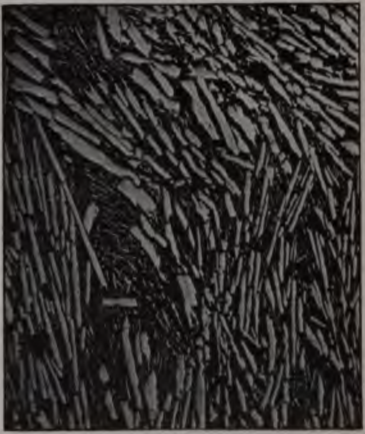


No. 7.

WASHED IRON AND SULPHUR.

Carbon	..	4·04%
Sulphur	..	3·97

Magnified 50 diameters.



No. 8.

WASHED IRON AND SULPHUR.

Carbon	..	4·06%
Sulphur	..	4·20

Magnified 50 diameters.

***PROCEEDINGS* STAFFS. I. & S. INST.**
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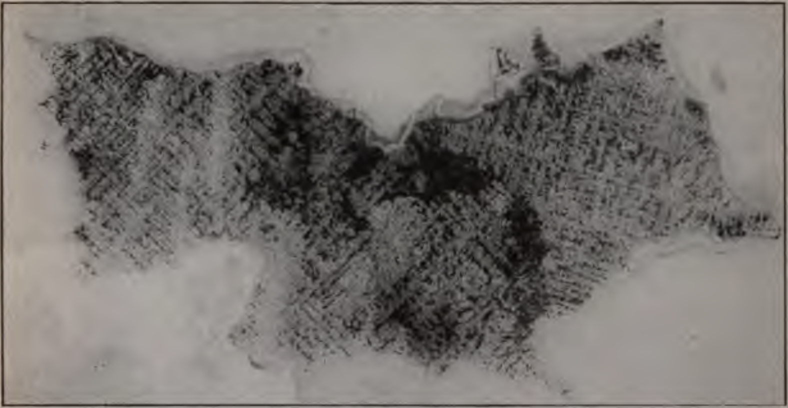
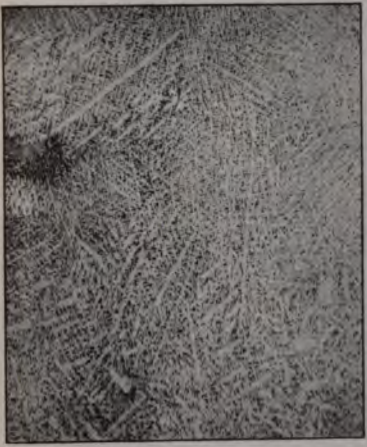
Mr. J. E. Stead's Paper.



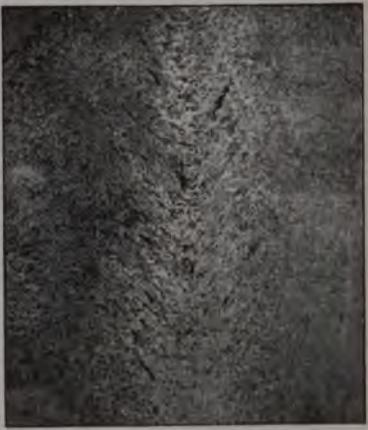
No. 9.

Three crystallites of Steel from large ingot. Cross section. Auto-sulphur print, showing how the Sulphur is imprisoned between the crystals and the primary spines. Natural size.



No. 10.

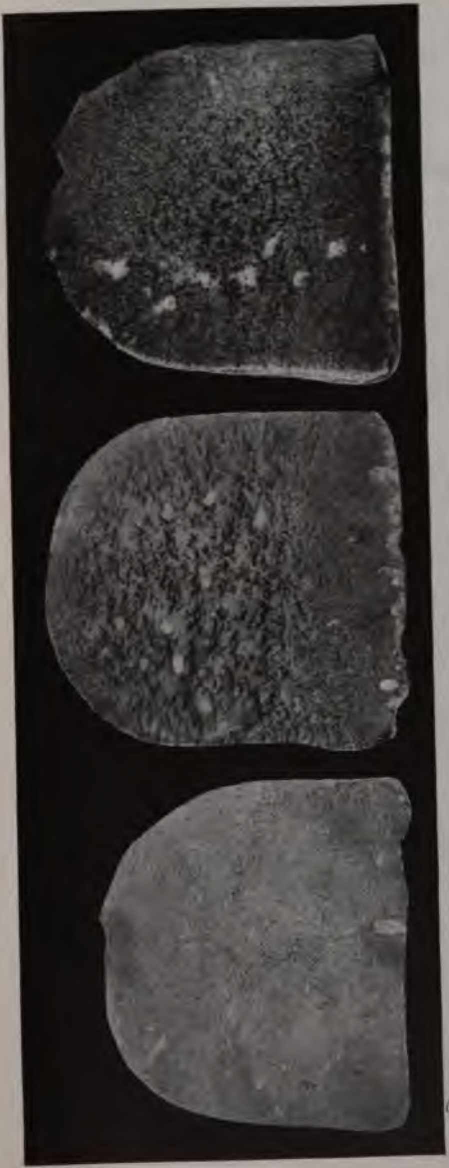
Section of large steel ingot. Central axis—near top. Auto-sulphur print, showing the crystalline spines free from Sulphur. The Sulphide is at the borders. Natural size.



No. 11.

Vertical section of large steel ingot near middle from auto-sulphur print, showing there has been sagging in the steel when plastic. Natural size.

Mr J. E. Stead's Paper.



No. 3 Foundry.

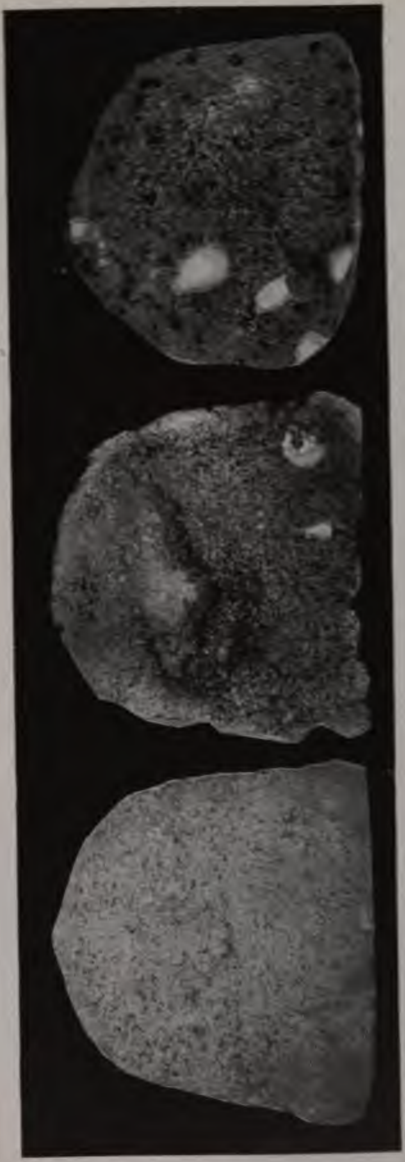
No. 4 Foundry.

No. 12.

No. 6. Forge.

Sections of Staffordshire Pig Iron, from auto-sulphur prints, showing that the tints are proportional to the Sulphur present. Half natural size.

Mr. J. E. Stead's Paper.



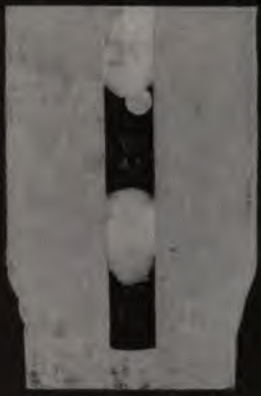
FOUNDRY 3. FOUNDRY 4. FORGE 4.

No 13.

Sections of Cleveland Pig Iron. Ormesby brand. From auto-sulphur prints. Half natural size.

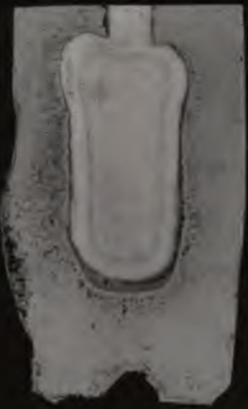
PROCEEDINGS STAFFS. I. & S. INST.
SESSION 1907-1908.

Mr. J. E. Stead's Paper.



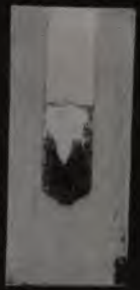
No. 14.

Section of a partially bored gun barrel, in which Oxysulphide of Iron had been heated at 1,200°. None of the Sulphide diffused through the steel. The black parts in the print represent the remaining solid Sulphide.



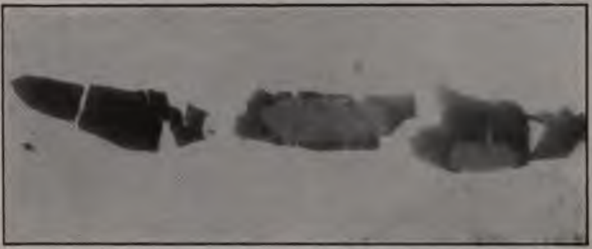
No. 15.

Section of a steel cylinder in which Sulphide of iron had been heated to near the melting point of steel. The large cavity shows that steel had been dissolved by the Sulphide



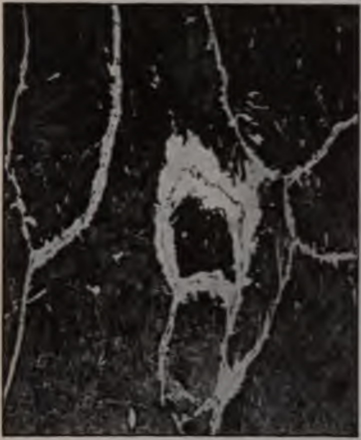
No. 16.

Section of a closed steel cylinder containing Sulphide of iron, heated for many hours above the melting point of Sulphide. No Sulphide passed through the steel. A plug was electrically welded into the upper part of the cylinder.



No 17.

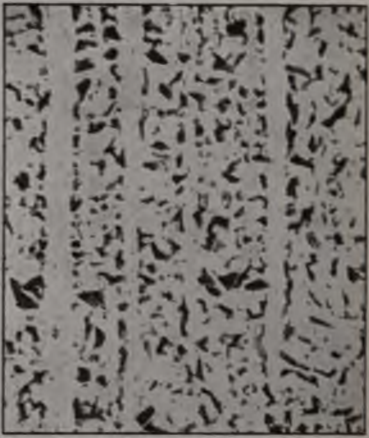
Section of forged steel showing inclusion of slag and Sulphide of Manganese. The dark portion is slag, the half-tone portion is Sulphide of Manganese, and the white portion is the polished steel.



No. 18

Section of steel casting, showing Sulphide inclusions in the middle of the Ferrite.

Magnified 50 diameters.

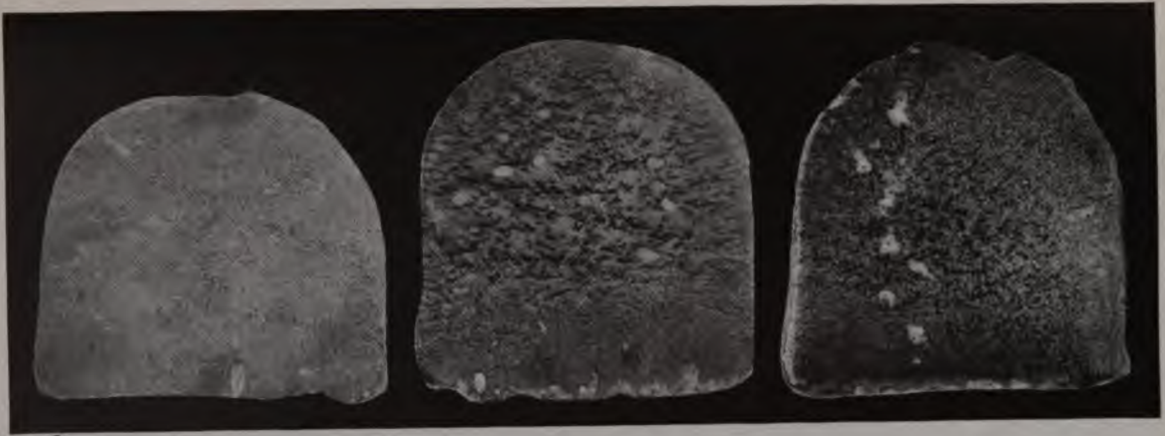


No. 19.

Rolled steel plate, with white bands of Ferrite, in the centre of which are lenticular particles of Sulphide of Manganese.

Magnified 50 diameters.

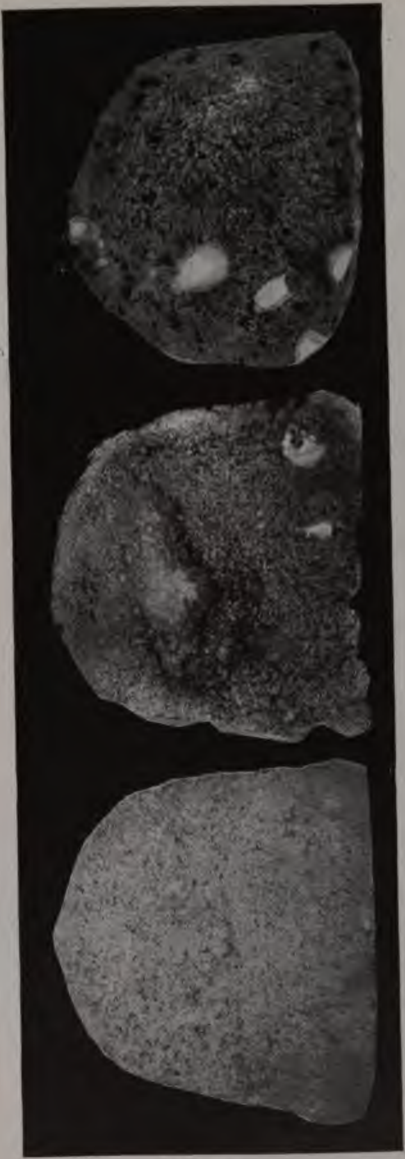
Mr J. E. Stead's Paper.



No. 3 Foundry. No. 4 Foundry. No. 6. Forge.

No. 12.

Sections of Staffordshire Pig Iron, from auto-sulphur prints, showing that the tints are proportional to the Sulphur present. Half natural size.



FOUNDRY 3.

FOUNDRY 4.

FORGE 4.

No 13.

Sections of Cleveland Pig Iron. Ormesby brand. From auto-sulphur prints. Half natural size.